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ORIGINAL ARTICLES.

On *Climacograptus inuiti* sp. nov. and its Development.

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(PLATES I–II.)

I. Introduction.

WHILE accompanying the Oxford University Hudson Straits Expedition in 1931 to Akpatok Island in Ungava Bay, North Canada, the writer found that in the horizontally bedded limestones of Ordovician age one stratum alone was graptolitiferous. This contained a vast number of individuals in all stages of development, nevertheless all of the same species. When treated suitably with acid, specimens could be isolated from the matrix and thus a complete ontogeny has been worked out.

II. Description of Species.

Climacograptus inuiti sp. nov.

Holotype.—Specimen figured in Plate I. (Sedgwick Museum Catalogue No. A 3518.)

Description of uncrushed specimen. Plate I.

Polypary.—Average length 15–20 mm.; maximum observed length 29 mm. Breadth at proximal end 0·75 mm. Rapid broadening distally to 1 mm. after which the polypary broadens very slowly to about 1·75 mm.

Cross Section.—Ovate.

Sicula.—1·5 mm. in length; visible length in adult specimen 0·5 mm.; diameter of aperture 0·3 mm.; furnished with two apertural spines and a virgella, all 0·5 mm. in length.

Thecae.—Twelve to fourteen in 10 mm.; form abruptly sigmoid with a tendency to expand distally; length 1·5 mm.; overlap half; free edges vertical; apertural margin undulate, and depressed internally; margin thickened. Mesial angle with prominent flange.

Impressed edge making an angle of 40° with base of thecal cup. Excavations wide and deep, being about 0·25 mm. in depth and of width equal to length of thecal free edges. Theca 1^1 with horizontally directed spine 0·5 mm. in length, originating immediately the theca assumes the vertical position; apertural margin slightly undulate; no flange. Theca 1^2 with apertural margin less undulate than in distal thecae and no flange.

Virgula.—Produced distally.

Affinities.—The excellent and undistorted preservation of this form makes difficult the comparison of it with crushed specimens. Nevertheless, the thecal form and especially the mesial flange, which is a structure unlikely to be completely obliterated in crushing, can be found to compare with no species that the writer has been able to trace; *Cl. innotatus* Nicholson, however, shows a vestige of such a structure.

Of British species it shows more similarity with *Climacograptus latus* Elles and Wood (Upper Hartfell Shales)[1] than with any other, having in common with this form the very gradual broadening of the polypary after the normal adult type of theca has been attained, the number and length of thecae, and also certain similarities in the proximal end. However, there are differences more essential than these common features: the apertural margins of the thecae in *Cl. latus* are more even; and the mesial angle, though markedly sharp, appears to bear no mesial flange; the excavations are less protracted distally. It is not without interest also that the number of proximal spines is figured as three and never as four; but it is more than likely that one apertural spine is lost in crushing, indeed, when the bilateral symmetry and balance in the metasicula is considered it seems probable that all Diplograptidae had two apertural spines and a virgella. The virgella in *Cl. latus* is longer than in *Cl. inuiti*, being 1 mm. in length.

From Scandinavia there is a form figured as *Climacograptus* sp. in one of Holm's plates (iii, fig. 23),[2] which is similar to this new species. This figure is of a portion of adult rhabdosome isolated from a limestone, and it shows a mesial flange, but not so prominent as in *Cl. inuiti*; furthermore, this flange continues round the margin of the excavation and joins the apertural margin of the preceding theca. Also the thecae are not so demarked from the rest of the rhabdosome as in the new species, where a definite groove occurs on a line with the interthecal septum. Nor is there so marked an excavation on the internal edge of the apertural margin.

The new species does not seem to approach to American species more closely than European. The nearest approximation is a figure of *Cl. lorrainensis* Ruedemann[1]; but here again, although there is a sharp mesial angle, no trace of a flange is visible; there is no excavation where the apertural margin meets the rhabdosome, and the free edges of the thecae are not vertical.

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[1] Elles and Wood, *Monograph of British Graptolites*, 205, fig. 135; and pl. xxvii, fig. 3.

[2] O. M. B. Bulman, "On the Graptolites prepared by Holm: i, Certain 'Diprionidian' Graptolites and their Development," *Arkiv för Zoologi*, Band 24A, No. 8, Stockholm, 1932, pl. iii, fig. 23.

The writer, in proposing the specific name *inuiti*, has taken the not unprecedented course of using the name of the inhabitants of the locality, the Eskimo of those parts referring to their race as the "Inuit".

Locality.—Akpatok Island, Ungava Bay, North Canada. Dr. Bell, of the Canadian Geological Survey, made the only other recorded landing of a geologist on the island, at the end of the last century,[2] and the fossils he collected were identified by Whiteaves[3] as comprising fifteen species. None of these, however, were graptolites.

Horizon.—The graptolitiferous band occurs some 450 feet up the succession of Akpatok limestones, and above it are beds barren except at the extreme top; but even here fossils are rare and poorly preserved.

An extensive collection of fossils was made from the limestones below the graptolite band, and these will form the material of further study. It is not possible at present to assign the graptolite to a definite horizon, which, in a paper of a purely morphological nature and dealing with a species apparently very limited in distribution, is not of especial import. Certain notes, however, are here appended. These demonstrate a horizon high in the (British) Ordovician (possibly Richmondian).

Whiteaves[3] assigned Bell's specimens to the Trenton, remarking that they were reminiscent of the Trenton of Red River, Manitoba; Bassler,[4] however, regards many of them as presenting a Richmondian facies.

Professor O. T. Jones has very kindly examined some Plectambonites (sens. lat.) in the writer's collection, and gives the opinion that in comparison with British species they show a stage of development which is probably more advanced than that of the typical *S. sericea*, which is derived from the middle part of the Lower Bala, and certainly not as advanced as forms from the Upper Bala. These were collected from all levels in the 450 feet of limestone below the graptolites.

Certain of the Trilobites also have been examined by Dr. Stubblefield, to whom the writer is greatly indebted for notes upon them. A form, not identical with *Ceraurinus icarus* (Billings) but closer to this than to any that Dr. Stubblefield has traced, occurs and may be indicative of Richmondian age; there is also a specimen that may possibly be *Ceraurus numitor* Billings, which is also

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[1] R. Ruedemann, *The Utica and Lorraine formations of New York*, ii, 1925, 63, fig. 52.

[2] R. Bell, *Rept. Geol. Surv. Canada*, x, 1897, 79.

[3] Whiteaves, *Amer. Jour. Sci.*, 4, xii, 1899, 433–4.

[4] R. S. Bassler, *U.S. Nat. Mus. Bull.*, 77, 1911, 36.

Richmond, but with this is found a form that may be the Trenton *C. pleurexanthemus* Green. It is difficult to draw conclusions on so small a number of identifications, especially as Foerste[1] considers that some of the Richmondian faunules may have had a northern origin; therefore such conclusions must remain for the completion of work on other material collected.

III. TECHNIQUE.

The graptolites of Akpatok Island are preserved in a chocolate-coloured limestone. The technique employed for their isolation from this matrix and subsequent maceration differs little from that employed originally by Wiman[2] and later with such remarkable success by Kraft.[3] Concentrated hydrochloric acid was used for isolation, and it was found extremely convenient to pick specimens off the large bubbles which bore them up; hence contamination by contact with the silt, which had an irredeemably soiling effect, was avoided. After careful washing on a cavity glass slide, specimens were macerated in concentrated nitric acid and potassium chlorate, which removed the black carbonaceous material and left the chitin[4] of the graptolites in orange transparency. In the case of adult specimens it was found necessary to use more dilute acid, since bubbles, formed by the removal of carbon from the interior, ruptured the rhabdosome. When sufficiently macerated, specimens were washed and left to dry in slight warmth on the slide, after which a drop of xylol was added and followed by Canada balsam and a cover slip which the hollow of the slides preserved from crushing the graptolite.

Longitudinal and transverse sections of thickness varying from 8–15 μ were made on a microtome after embedding the unmacerated graptolite in wax.

IV. ONTOGENY.

Specimens in every stage of development were mounted and from these the following ontogeny has been made out. All figures and plates (except the diagram in Fig. 24 and Fig. 26) have been drawn with the Parkes-Lapworth drawing apparatus and detail added from the microscope. All specimens figured or mentioned are preserved in the Sedgwick Museum, Cambridge. Numbers in square brackets refer to the catalogue of this collection.

The Prosicula[5] (Figs. 1–5 and 24*a*).—The youngest individual secured (Fig. 1*a*) had the form so well described by Kraft[1] as "of bottle shape but with a closed mouth and open base"; in length it was 0·5 mm. The neck is the inception of the nema, or *nema prosiculae* of Kraft,[2] and is exceedingly fragile, rarely surviving maceration. Little can be discerned of the structure beyond two essentials which occur in the wall of the prosicula. Of these, the more striking are four longitudinal thread-like structures[3] (Figs. 1*a*, 1*b*, *p*), which continue up into the nema as two threads, and bifurcate soon after the sudden increase in diameter of the prosicula. These longitudinal threads taper to extreme fineness but, nevertheless, do reach the margin of the aperture. Besides these threads, a very faint and narrow spiral band[4] can be traced from the nema down the body of the prosicula. The spiral is very gradual, and where the bands are best observed they might be described as sub-parallel to the margin of the aperture.

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[1] A. F. Foerste, *Geol. Surv. Can. Mem.*, 138, 1924, 12.

[2] C. Wiman, "Ueber Diplograptidae Lapw.," *Bull. Geol. Inst. Univ. Upsala*, i, 2, 1893.

[3] P. Kraft, *Pal. Zeitschrift*, vii, 1926, 1–4.

[4] P. Kraft, op. cit., p. 220.

[5] Kraft, op. cit., 222.

The substance of the prosicula is at this stage extremely slight, indeed, at the base of the nema, it is almost completely transparent. It is not surprising then that the subsequent growth of the prosicula is concerned with strengthening. A series of secondary strengthening rods (Fig. 2, *r*) are now intercalated between the primary four. These do not reach the nema, but being thickest at the apertural margin, taper gradually until they disappear at the level where the prosicula begins to lessen its diameter. At the same time the spiral band (Fig. 2, *s*), a mechanical essential if a hollow tube is to withstand pressure from without, becomes more accentuated. The nema lengthens (Fig. 2), and the distal portions of the primary rods can be seen to extend for all its length. The margin of the aperture thickens.

The Metasicula[5] (Figs. 3–6).—Subsequent to this stage of growth reached by the prosicula, chitinous tissue begins to be laid down at the margin of the aperture. This tissue, which is the commencement of the metasicula, is concentrated at first within a very short length and grows in lunate fashion downward for the length of three growth lines; the second band of tissue is of less lateral extension than the first, and hence a neck is produced. The third band commences in a bulbous fashion (Fig. 3*a*, *v*), but soon ceases to swell and grows downward at a practically constant width as the inception of the *virgella*[6] (Fig. 3*b*, *v*), the strengthening process of the metasicula. Thus it may be seen that the virgella is in no way morphologically

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[1] Kraft, op. cit. "Die Prosicula . . . hat eine Gestalt, die am besten mit einer zylindrischen Flasche zu vergleichen ist, deren Hals geschlossen, deren Boden aber geöffnet ist."

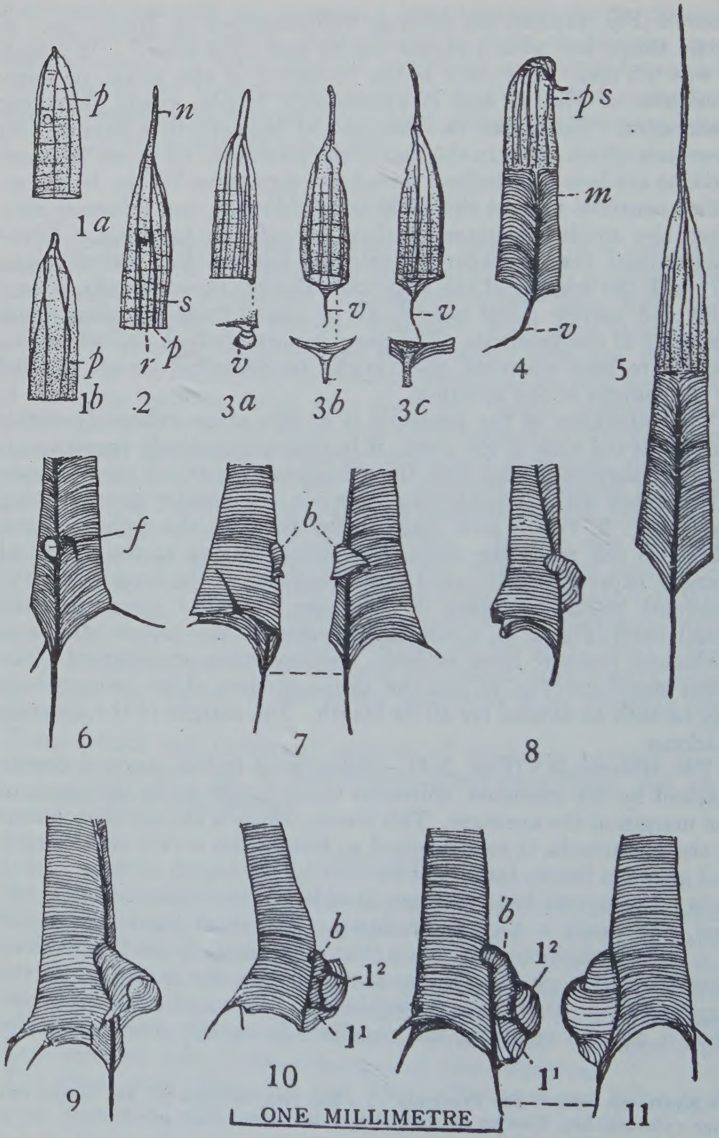
[2] Kraft, op. cit., 223.

[3] Kraft, op. cit., "Längsverstärkungsleisten."

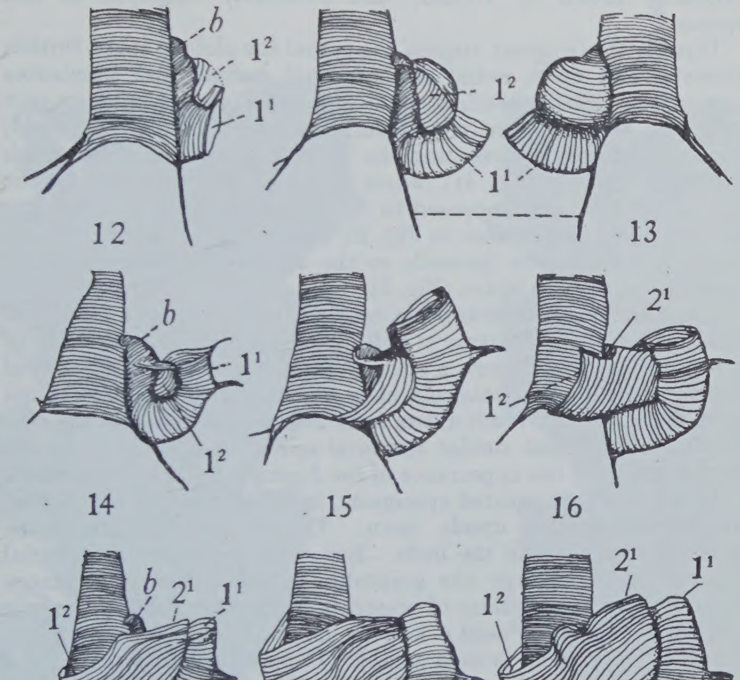
[4] Kraft, op. cit., "Schraubenlinie."

[5] Kraft, op. cit., 226.

[6] G. L. Elles, "The Graptolite Faunas of the British Isles." *Proc. Geol. Assoc.*, 1922.



FIGS. 1–11.—Camera lucida drawings of microscope preparations to illustrate the ontogeny of *Climacograptus inuiti* sp. nov. *b*, bud; *f*, foramen; *m*, metasicula; *n*, nema; *p*, primary longitudinal threads; *ps*, prosicula; *r*, secondary longitudinal threads; *s*, spiral band; *v*, virgella; 1^1, first theca; 1^2, second theca. Note: In Figs. 6–11 the prosicula is omitted. [A 3519–3532.]



Figs. 12–21.—Camera lucida drawings of microscope preparations to illustrate the ontogeny of *Climacograptus inuiti* sp. nov. Lettering as in Figs. 1–11. All are reverse views except 13*b* and 21*b*. [A 3533–3542.]

connected with the longitudinal threads of the prosicula, a fact originally shown by Wiman,[1] and admirably displayed in this species.

Directly the incipient virgella has passed the globose stage, further tissue is laid down round the apertural margin and terminates against the virgella, bending slightly proximally to envelop its root (Fig. 3*c*). Growth of the metasicula then proceeds band after band, the virgella always preceding the growth of the aperture which inclines towards it (Fig. 4); where the bands of tissue meet on the side of the metasicula opposed to the virgella, there is a zigzag line of junction (cf. appearance in Fig. 25, *m* and the border of theca 1^2, Fig. 19). As growth proceeds so the aperture of the metasicula continues always to widen (Fig. 5).

Lengthening of the metasicula ceases after it has grown for 1 mm. The margin of the aperture is still more extended on either side of the virgella, which is now a spiny structure, and the last stages of development in the metasicula have produced two apertural spines (Fig. 6). Herein *Cl. inuiti* differs from *Diplograptus gracilis* Roemer. Kraft observed that similar apertural spines were produced in the metasicula after the appearance of the foramen for the initial bud.[2]

It is found that isolated specimens, in which the first two thecae are immature, float upside down. This no doubt is due to the presence of air within the buds. But since protoplasmic material such as would occupy the graptolite is not a heavy substance (especially in the medium of water) it seems that with long nema the individual would need a keel to maintain its vertical position. Possibly the virgella is such a keel. It may be assumed that the vertical position is essential if the adult is to attach itself to floating material by the tip of the nema. The apertural spines may similarly have served to counterbalance the weight of the early buds, which lie opposite a point midway between them. Were they to be merely organs of protection their presence would be expected as the metasicula grew and not as a completion of it; and were they merely excess excretion of chitin they would be far less constant in occurrence from genus to genus. Thus the fundamental difference between the structure of the metasicula and that of the thecae might be explained as an expression of different mechanical need.

The First Theca (1^1).[3]—The first evidence of a true [4] theca is a foramen that appears in the metasicula immediately on the reverse [5] side of the virgella, some eighteen growth-layers distant

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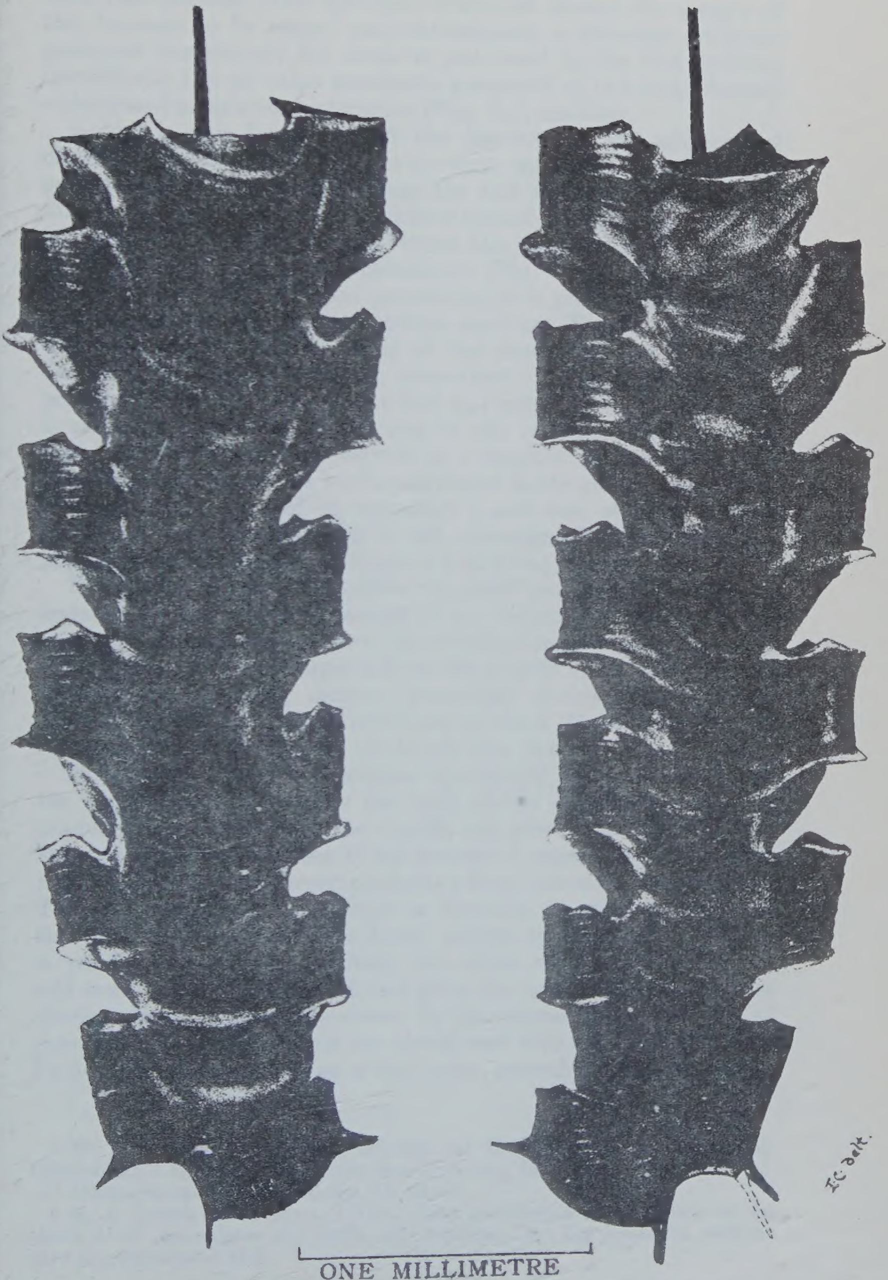
[1] C. Wiman, op. cit.

[2] Kraft, op. cit., 229.

[3] Nomenclature of G. L. Elles (*Quart. Jour. Geol. Soc.*, liii, 1897, 189).

[4] Kraft regards the metasicula as a theca, pointing out that it has essentially the same structure. Op. cit., 228.

[5] The sicula is seen in reverse view if it be placed with nema directed distally and the virgella on the right hand.



Climacograptus inuiti sp. nov.

[*To face p. 8.*

from the aperture. One specimen examined showed the margin of this foramen to be ragged and unthickened, a situation evidently produced immediately the sicula is punctured by the first budding individual; but all other specimens preserved at this stage display a thickened margin to the foramen (Figs. 6, *f*, and 24*a*).

A bud is now formed about the foramen by the addition of chitin at the margin, except on its most apertural sector, so that growth almost immediately brings the bud to open in a proximal direction and with part of its boundary formed by the sicula (Figs. 22, 24*b*, and 29*b*). The bud then traverses the virgella and comes to lie on the obverse side of the metasicula (Fig. 7, *b*), down which it begins to grow—the margins proceeding at a greater rate than the centre, thus giving a slightly oblique aperture (Figs. 8 and 24*a*, *b*). The bud does not lie in a fold of the sicula such as Whittard[1] describes for *Glyptograptus* aff. *tamariscus*: "The aperture which permits connection between the bud and sicula in *G.* aff. *tamariscus* is small in proportion to the size of the cavities which it joins, thus the fold may have served as a support to the bud." In *Climacograptus inuiti* the bud is ankylosed to the sicula, so that this structure forms part of its boundary; and also, since it is more rotund in cross section than *G.* aff. *tamariscus*,[2] presumably the support here was sufficient without a fold in the sicula.[3]

The Second Theca (1^2).—After the bud has traversed half the distance to the apertural margin of the sicula, the portion of its aperture furthest remote from the virgella tends to grow outward, while on its apertural margin a horn-like growth arises, and, growing towards the opposing margin, eventually divides the aperture. Thus the initial bud, which continues as theca 1^1, has given rise to the second theca 1^2 (Figs. 9, 10, 11, 22, 24*a*, 24*b*, *f*).

The incipient theca 1^1 continues aperturally down the margin of the virgella until it reaches the limit of the metasicula, where it gradually turns away from the virgella and grows outward (Fig. 12). Meanwhile, growth in theca 1^2 has proceeded, especially on the outer margin which, growing over, produces a hood-like structure (Fig. 13). Theca 1^1 continuing its change in direction to open distally has therefore to bend round the lower margin of theca 1^2. Directly it reaches the vertical position the theca ceases temporarily to add considerably to its length and gives rise to a lateral spine. This slowing down in growth is shown by the concentration of lines of growth which continue from the thecal wall into the spine (Fig. 14). Following on the production of this spine, growth continues distally.

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[1] W. F. Whittard, "On the Structure of *Glyptograptus* aff. *tamariscus* (Nicholson)," *Ann. Mag. Nat. Hist.*, Section 9, xix, 1927, 471.

[2] Whittard, op. cit., pl. xiii, figs. 61, 63, 66.

[3] K. A. Davies (GEOL. MAG., LXVI, 1929), mentions a similar infold in the sicula of *Gl. persculptus* and *Ortho.* aff. *truncatus*, but his published sections give no evidence for this.

Two cases of abortive attempts to produce a second lateral spine in the first theca were observed (Fig. 14).

The Third Theca (2^1) *and Subsequent Thecae.*—Theca 1^2 grows through the crook of the first theca and, crossing the proximally directed portion of theca 1^1, comes to rest on the sicula, the more proximal margin being in advance and lying along the apertural margin (Fig. 15). But just as the initial bud was not a complete tube, part of its boundary being formed by the sicula down which it grew, so in the young theca 1^2 the aperture is always completed by that particular structure it is traversing. It is when the upper margin crosses from the bud of theca 1^1 to the metasicula that the bud of the individual to secrete theca 2^1 must have been produced; thus there is a foramen between the ankylosis of theca 1^2 to the initial bud and that to the metasicula (Fig. 16, 2^1).

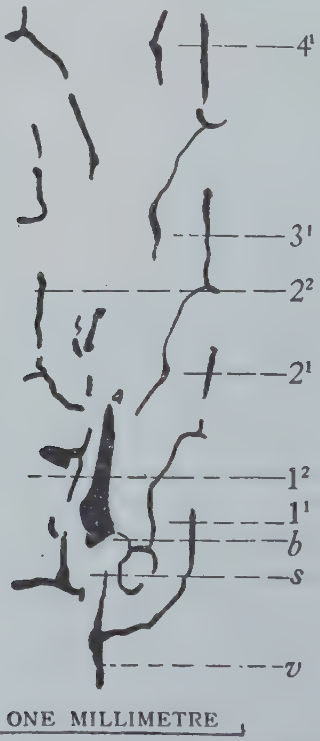
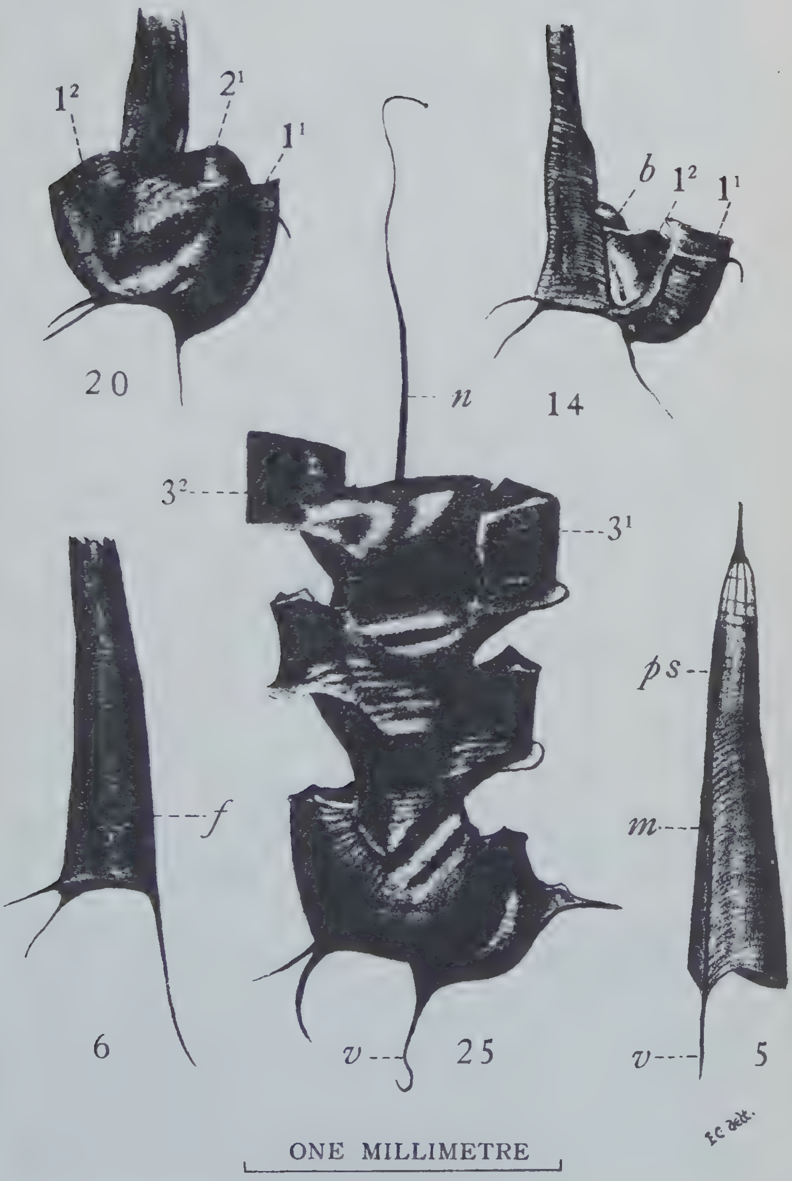


FIG. 22.—Longitudinal section of *Climacograptus inuiti* sp. nov. from a series cut on a microtome at 15 μ to show the relation of the initial bud to the sicula. *b*, initial bud; *s*, sicula; *v*, virgella. The thecae are numbered as by the convention. [A 3550.]



YOUNG INDIVIDUALS OF *CLIMACOGRAPTUS INUITI* sp. nov.

[*To face p.* 10.

In this species the production of theca 2^1 is morphologically delayed when compared with the case in *Diplograptus gracilis* Roemer, described by Kraft,[1] where that bud is produced from theca 1^2 when still in the crook of theca 1^1, although theca 1^2 has already reached the apertural spine of the metasicula.

Theca 1^2 continues to grow across the sicula, the lower margin keeping to the apertural margin until the first apertural spine is reached, and then turning distally and slightly outward. Meanwhile the upper margin tends obliquely across the sicula until slightly more than half the circumference is traversed, whereupon the theca commences to form an apertural margin that is complete—showing the same zigzag junction of contemporaneous growth lines as already noticed in the metasicula (Fig. 19). It then grows distally, embracing a small part of the obverse view of the sicula as well as the entire reverse periphery, and showing herein the tendency to invest the sicula which is to be realized more fully in the later thecae. However this phenomenon of investiture, presumably a protective measure,

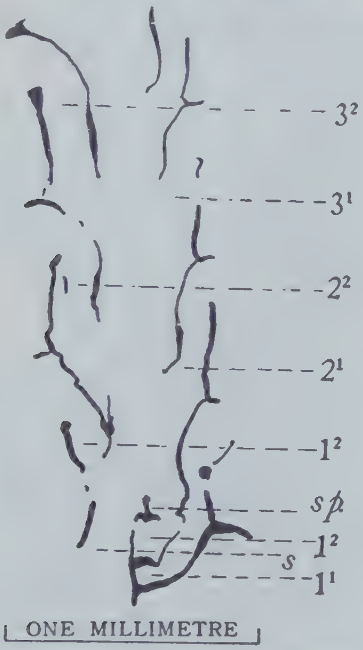


FIG. 23.—Longitudinal section of *Climacograptus inuiti* sp. nov. from a series cut on a microtome at 15 μ to show interthecal septum (*sp*) between theca 1^2 and theca 2^1. Lettering as in Fig. 22. [A 3550.]

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[1] Kraft, op. cit., 230, and pl. vii, ii.

is not developed to any great extent in Climacograptids,[1] and in this species a third of the entire length remains uncovered throughout the life of the polypary.

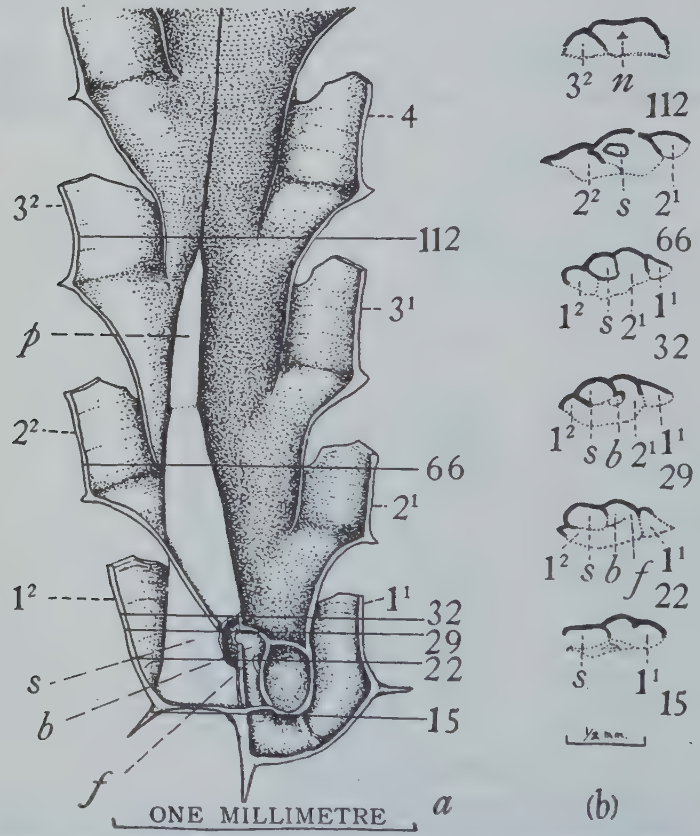

Fig. 24.—(*a*) Simplified dissection of *Climacograptus inuiti* sp. nov. drawn on a camera lucida outline. The numbered horizontal lines represent the level at which the transverse sections (*b*) are taken. (*b*) Transverse sections of the rhabdosome. Taken from a series cut on a microtome at 15 μ: *b*, initial bud; *f*, foramen from theca 1^1 to theca 1^2; *n*, nema; *p*, prosicula; *s*, sicula. Note: Dotted portions of the sections are omitted in the dissection *a*. [A 3551–2.]

The first two thecae show none of the specific characteristics of the adult thecae, the first of which is theca 2^1. This theca grows from its inception up the inner margin of theca 1^1 (Figs. 17–18), and upon reaching the termination of that theca tends to grow outward, at first gradually then suddenly to produce, with a clustering of growth lines, the mesial flange (Fig. 25). While the margin on the side of the first theca is growing up and sometimes investing the virgella above the initial bud, the other margin follows that of theca 1²

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[1] A perusal of the species of *Climacograptus* described in the *Monograph of British Graptolites* shows that but two have an embedded sicula. See also Whittard, op. cit., 475.

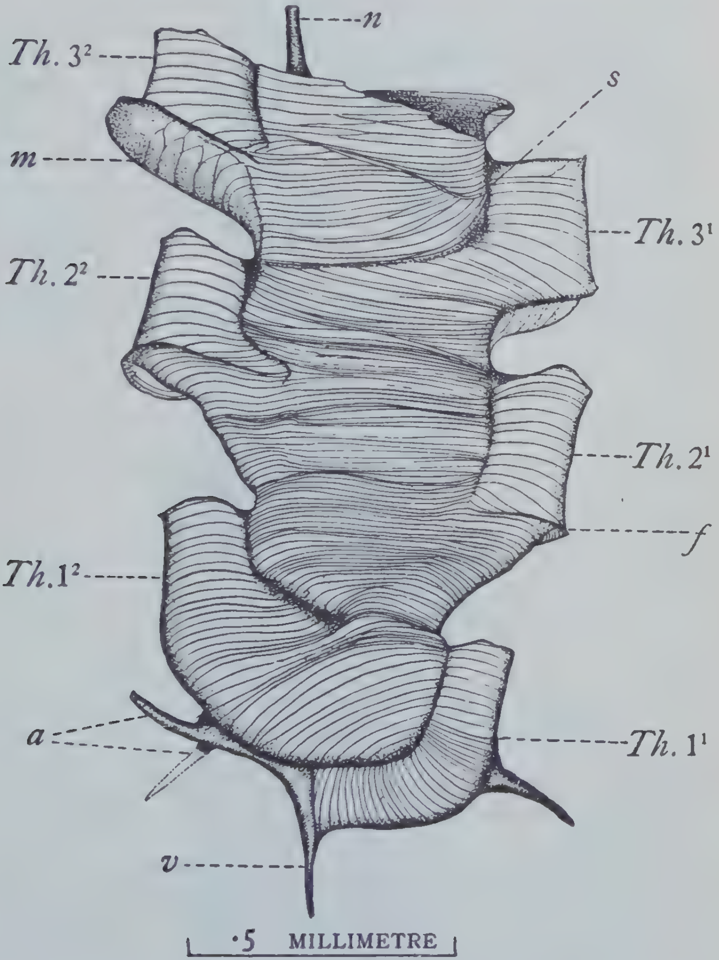

FIG. 25.—Camera lucida drawing of a young individual of *Climacograptus inuiti* sp. nov. macerated to show lines of growth. *a*, apertural spines; *f*, mesial flange; *m*, impressed edge forming the thecal floor; *s*, interthecal septum; *v*, virgella. [A 3543.]

obliquely across the sicula, the two thecae being separated by a long interthecal septum [1] (Figs. 19, 20, 21, 23, 24*a*, $24b_{32}$).

As growth continues with theca 2^1 that portion of its wall lying in the region of theca 1^2 adds growth layers of chitin rapidly as a foundation of theca 2^2. Such growth layers are seen to wedge out toward the centre of the polypary in an adult specimen. Theca 2^2 has barely produced a mesial flange before theca 2^1 is practically completed and has an interthecal septum forming the interior boundary of the theca. The theca subsequent to theca 2^2, 3^1, is produced by rapid growth laterally just as theca 2^2 from 2^1. Hence it can be seen that thecae have their origin in the preceding thecae on the opposite side of the rhabdosome, and growth lines in the rhabdosome wedge out alternately on one side and the other (Figs. 25 and 26).

It is interesting that, while in early Diplograptids the third theca (theca 2^1) commences by growing horizontally or proximally and gradually assumes a distal direction of opening by turning through 90–180°,[2] in this and other late forms it grows in a distal direction from the first.

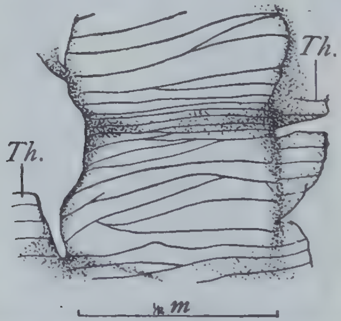

FIG. 26.—A portion of rhabdosome of *Climacograptus inuiti* sp. nov. macerated to show lines of growth. *Th.*, inmost portions of thecae. [A 3544.]

The Interior of the Rhabdosome.—Fig. 27 illustrates a dissection of a polypary made in the matrix. The interthecal septa are apparent and can be seen all to have a single corrugation toward their base. This seems to be continued across the rhabdosome as a strengthened area with clustered growth lines (cf. Fig. 25). The interior of the thecal walls exhibit no structure nor irregularity upon their surfaces. Certainly no traces of muscle scars such as are claimed by

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[1] O. M. B. Bulman, "On the Graptolites prepared by Holm: i, Certain 'Diprionidian' Graptolites and their Development," *Arkiv för Zoologi*, Band 24A, No. 8, 1932, 5.

[2] For example *Cl. orthoceratophilus*; Bulman, op. cit., 18, fig. 9*a*, pl. iv, fig. 18.

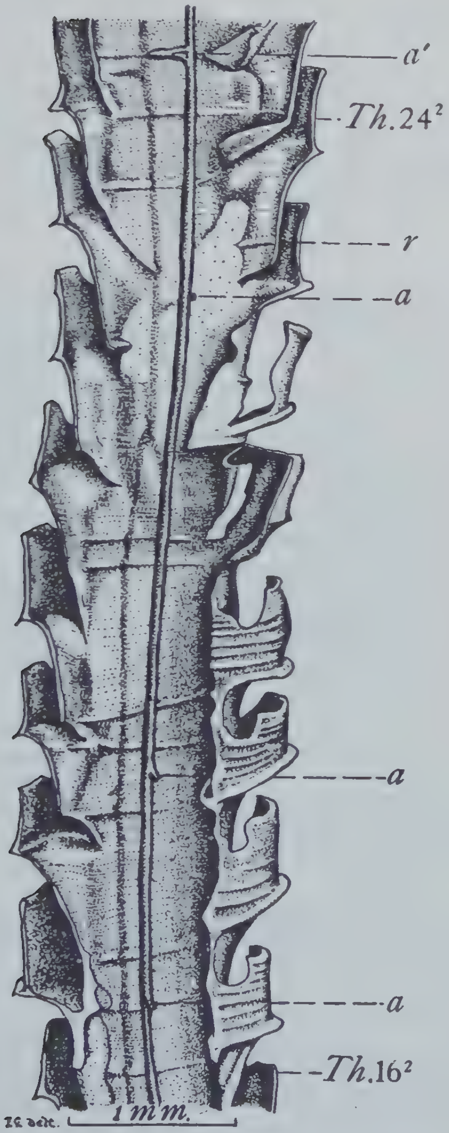

FIG. 27.—Distal thecae of *Climacograptus inuiti* sp. nov. dissected from the observe side while still partially embedded in the matrix. Camera lucida drawing; detail added with a binocular microscope. *a*, rods of support on the virgula; *r*, corrugation on the interthecal septum. [A 3559.]

Drs. Ulrich and Ruedemann[1] to occur in *Cl. typicalis* Hall and "*Glossograptus*" *quadrimucronatus* are to be found in this species.

V. The Virgula.

While these thecal additions are going on growth continues in the prosicula. The nema of the prosicula lengthens into a hollow rod-like structure, the *nema*[2] or virgula, whose internal cavity is continuous with that of the prosicula. Thus in a young polypary which was just commencing to produce theca 3^1, the length of the virgula was 3 mm. while that of thecal elements alone was only 1·3 mm. [A 3556.]

Serial transverse sections show the four primary longitudinal rods of the prosicula (*vide supra*) gradually waning in diameter, when traced distally, and eventually disappearing and leaving the virgula circular in cross section and hollow (Fig. 23). The disappearance of all the rods does not take place at the same time, and thus the virgula may be of triangular shape where it is left with three (Fig. 24*b*, Section 112). In some sections of unmacerated nema, two concentric layers can be seen : a thick inner one and a thin rind without. The granular substance described by Whittard[3] as partially infilling the sicula and nema in *Glyptograptus* aff. *tamariscus* has not been found in this species.

In undamaged specimens the virgula always extends distally beyond the polypary. In this species there is no attachment of the virgula to the interthecal septum nor deviations of it from the straight. Single rod-like structures are, however, developed at right-angles to the virgula connecting it with the rhabdosome wall (Fig. 27*a*). In no case of either section or dissection have these rods been observed to reach the interthecal septum, and there is only one particular instance (*a'*, Fig. 27) in which there is any possibility that such a structure may have done so. In the specimen dissected to give Fig. 27 these supporting rods occur at levels near the base of the interthecal septa of thecae 7^2, 11^1, 14^2, 17^2, 20^2, 23^2, 26^2. In all cases these rods came off singly, connecting the virgula to one wall of the rhabdosome.

Fig. 28, however, shows in serial section the only case where one immediately succeeds another from the opposite side. In Fig. 28, No. 12, it is seen that the rod is somewhat spongy in internal structure.

A consideration of the significance of these supports can only be speculative. Attachment of the virgula to the rhabdosome was in Diplograptids effected in two fashions. These are admirably displayed in certain plates by Holm, which with explanatory text by

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[1] Ulrich and Ruedemann, *Bull. Geol. Soc. Amer.*, xlii, 1931.

[2] G. L. Elles, "Graptolite Faunas of the British Isles," *Proc. Geol. Assoc.*, 1922.

[3] Whittard, op. cit., 471.

Dr. Bulman are in the process of publication.[1] The writer is greatly indebted to the latter author for his kindness in allowing perusal of that work while still in proof. Here, Fig. 3 illustrates a dissection of *Climacograptus scharenbergi* Lapw. with a zigzag septum, which in its lateral inclinations fuses to the base of the interthecal septa; but since the latter structure has an arcuate margin, the septum only succeeds in reaching its outer edges. Now at the angles of the septum where such ankylosis has occurred there is a thickening which continues inward to the virgula. The macerated specimen

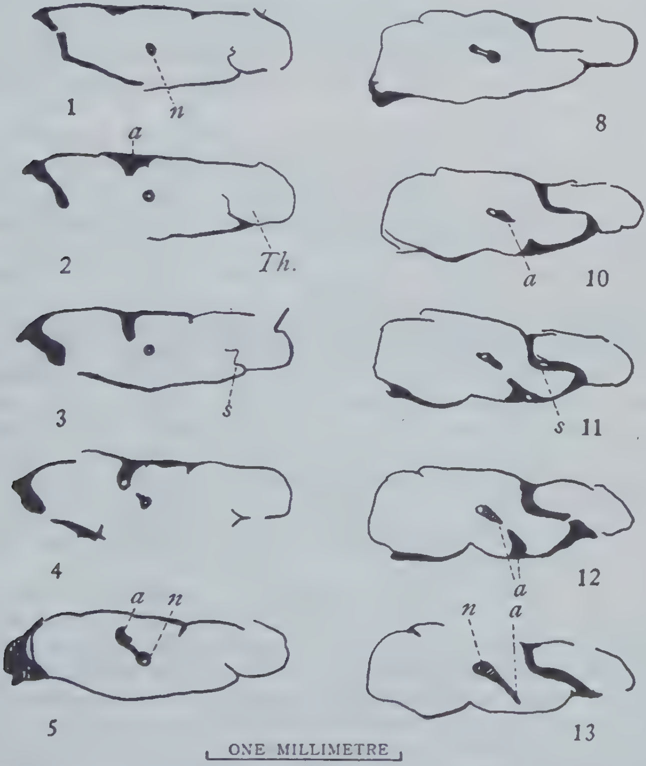

Fig. 28.—Serial transverse sections of an adult rhabdosome of *Climacograptus inuiti* sp. nov. cut on a microtome at 8 μ to show the origin and destination of the virgular supports. *a*, virgular supports; *n*, virgula; *s*, interthecal septum; *Th.*, theca. [A 3555.]

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[1] O. M. B. Bulman, "On the Graptolites prepared by Holm: i, Certain 'Diprionidian' Graptolites and their Development," *Arkiv för Zoologie*, Band 24A, No. 8, Stockholm, 1932.

(Plate I, Figs. 27–9) shows the thickened elements remaining alone. These consist of the virgula and structures of an angular U-shape attached to the virgula at their apices and alternating up its length. These represent the thickenings already noted as occurring at the base of the interthecal septa. Each branch of the U is seen to consist of two lengths : one proceeding from the virgula to meet the rhabdosome wall, and another meeting this almost at its termination and extending laterally to form the basal margin of the interthecal septum. The latter structure may be regarded morphologically as part of the interthecal septum, while that lying at right angles to it as septal in origin.

Another septate form figured as *Climacograptus* sp.[1] in scalariform view shows straight rods traversing the polypary in an obverse-reverse direction and fused to the virgula at their centre. These presumably represent the septally secreted portion of the U-shaped structure seen in *Cl. scharenbergi.*

The other way in which the virgula can be attached is seen in aseptate forms. Holm's plates[2] show admirably how that in *Orthograptus gracilis* Roemer the bases of the interthecal septa are produced proximally to fuse with the virgula, which is itself fused at the ankylosis. Not every interthecal septum reaches the virgula. The thickening of attachment in the virgula in this case is in a plane at right angles to that of the cases cited above. Wiman[3] noted this irregular attachment and figured portions of a virgula with cross processes of attachment. Hall,[4] furthermore, in his "Ideal longitudinal section" of *Cl. typicalis* postulates a prolongation of the basal margin of the "cell partitions" (= interthecal septa) which attaches to a straight virgula.

To return to the rods of attachment in *Cl. inuiti* : it has been stated that they lie at right-angles to the plane common to the interthecal septa and virgula, hence they appear to represent transverse rods seen in *Climacograptus* sp. of Holm and that portion of the U-shaped structure in *Cl. scharenbergi* that is produced by the septum. That the rods occur roughly on a level with the bases of certain interthecal septa in *Cl. inuiti* does not contradict a postulation of septal—as opposed to interthecal—origin, for in *Cl. scharenbergi* both types of supports seem to arise in conjunction and of necessity at such latitudes. Nevertheless, the rods appear certainly to be vestigial, since they occur irregularly and singly, each several rod only connecting the virgula with one wall of the rhabdosome.

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[1] Bulman, op. cit., pl. 1, figs. 27–9.

[2] Bulman, op. cit., pl. v, 23, 24 ; pl. vii, fig. 17 ; and pl. vi, 10, 11, 12.

[3] Wiman, "Ueber Diplograptidae Lapw.," *Bull. Geol. Inst. Univ. Upsala,* i, 2, 1893.

[4] Hall, "Graptolites of the Quebec Group," *Geol. Surv. Can.,* pl. A, fig. 9, 1865.

VI. Acknowledgement.

The writer wishes to express his gratitude to Professor O. T. Jones, F.R.S., for his opinion on horizon and for reading this manuscript; Miss G. L. Elles, D.Sc., he wishes to thank for the kindness of helpful criticism with regard to the manuscript; he is especially indebted to Dr. O. M. B. Bulman for valuable suggestions and criticisms offered throughout the progress of this work. Finally he wishes gratefully to acknowledge grants from the Governing Body of Magdalene College and the Worts Fund in Cambridge.

EXPLANATION OF PLATES I AND II.

Plate I.

Climacograptus inuiti sp. nov. Obverse and reverse views of proximal end. Holotype. [A 3518.]

Plate II.

Climacograptus inuiti sp. nov. Camera lucida drawings of young individuals. The numbers correspond with similar stages in ontogeny illustrated in the text-figures: *b*, initial bud; *f*, foramen; *m*, metasicula; *n*, nema; *ps.*, prosicula; *v*, virgella. [A 3545–9.]

June, 1932.

The Uplift of Barbados.

By C. T. Trechmann, D.Sc., F.G.S.

(PLATES III AND IV.)

THE coral capped or fringed islands of the tropics afford many problems for students of the later formations. In the West Indies each island differs from another in structure. Barbados stands alone among them in its seaward position, the general uniformity of its covering of coral rock and the height, 1,100 feet to which the coral rock has been raised. The formation of this coral rock, which reaches 240 feet in thickness, its uplift, the denudation of it off the Scotland area, and the deep ravining and erosion of both it and the Bissex Hill beds, Oceanic chalks, and Scotland beds is entirely so far as one can ascertain a feature of Pleistocene time.

The formation of the coral rock covering and its uplift has been to me a puzzling problem. On first thoughts nothing could seem simpler than the views expressed by J. B. Harrison and A. J. Jukes-Browne [1]:—

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[1] *Geology of Barbados.* Published by authority of the Barbadian Legislature, 1890, 27.

"Each of these platforms was once a fringing coral-reef like that which now surrounds the greater part of the island, and they now present a succession of steps or terraces, of varying width, rising one above another from the sea-level to a height of nearly 1,100 feet in the centre of the island; each step in this ascent being of older date than the one below it."

Professor J. W. Spencer[1] on the other hand claims that there are limestones of Oligocene age akin to the Antigua limestone, near Consett Point and elsewhere in Barbados, and he certainly has some justification for his views, as there are old-looking limestones at that place. Spencer's views were rejected by J. B. Harrison,[2] who asserted that all the limestones are Pleistocene.

After studying the fossils of the coral rock I am convinced that neither of these views is precisely correct. Harrison's view fails to account for the denudation of the Scotland area and Spencer's is not supported by fossil evidence.

The sea cliffs of coral rock at the north end of the island against which the Atlantic rollers beat with great force in rough weather or those at the Crane or Ragged Point on the south coast appear just as old and indurated as the cliffs along the escarpment at Hackelston's Cliff or other places at high elevations. Far from having the appearance of recently formed reefs they look like a formation of appreciable geological antiquity.

Professor W. M. Davis[3] speaks of the "aberrant island of Barbados", and further on (p. 218): "The course of the Atlantic marginal belt was altogether unexpected, yet it seems to be well certified in spite of the aberrant case of Barbados, the reconciliation of which with its neighbours must be regretfully left to the future."

It is clear to me that the uplift of Barbados has not been a purely vertical one but has been accompanied by an oblique thrust or sequence of thrusts exerted from the west and also from the south, away from the relatively shallow shelf of Venezuela and Trinidad and towards the extensive deep of 3,000 fathoms or more that lies to the north-east of Barbados and east of Barbuda and Guadeloupe, or in the direction of the convexity of the Antillean volcanic arc.

The force of uplift seems to have been repeated from the west and south-west extending outwards but with diminishing intensity. This differential uplift has caused the higher part of the island to have a pitch or tilt towards the east and north-east. The effect of this has been that in the central higher parts the covering of coral rock has weakened and cracked away along the sinuous line of the escarpment that overlooks the Scotland district and its fragments have been sent sliding in broken fragments down the slippery slopes of the Oceanic and Scotland beds towards the sea.

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[1] *Quart. Jour. Geol. Soc.*, lviii, No. 229, 1902, 354–367.

[2] *Quart. Jour. Geol. Soc.*, lxiii, No. 251, 1907, 319.

[3] *The Coral Reef Problem*: Amer. Geog. Soc., Publication No. 9, 1928, 208.

The St. Lawrence or Christchurch elevation, an elongated dome or ridge reaching 400 feet in elevation, that lies east and west at the south end of the island is a later independent uplift apparently with a thrust from the south, as it presents a slight escarpment along its northern edge. Harrison and Jukes-Browne (p. 28) hold the view that the Christchurch ridge was an independent island when the sea was at the level of the 200 ft. contour, a view evidently based on the idea of a vertical uplift.

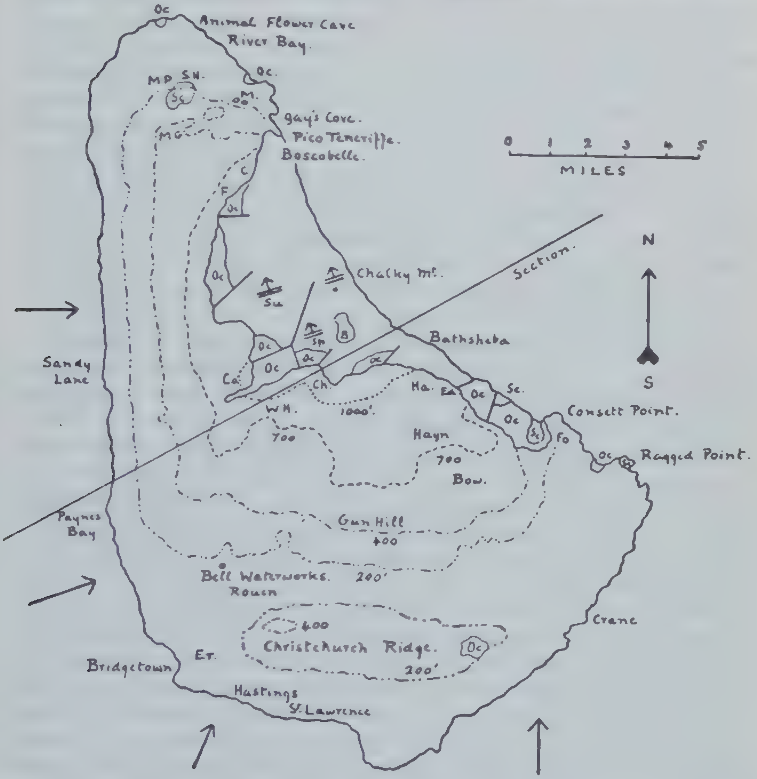

FIG. 1.—Sketch-map of Barbados. Showing coral rock contours at 200, 400, 700, and 1,000 feet. Sc., Scotland Beds; Oc., Oceanic Series. Localities: M.P., Mount Poyer; S.H., Spring Hall; M., position of undercut mushroom-like rocks; M.G., Mount Gilboa; C., Cherry-tree Hill; F., Farley Hill; Ca., Canefield; Ch., Chimborazo; W.H., Welshman's Hall; Ha., Hackleston's Cliff; Ed., Edgecliff; Hayn., Haynesfield; Bow., Bowmanston Waterworks; Fo., Fortescue; Er., Erdiston; Su., Sunbeam; Sp., Spa; B., Bissex Hill. Arrows represent approximate dip of Scotland Beds. The line of section is that represented in figure. Arrows outside the island indicate the supposed direction of thrusting that accompanied the uplift.

A great collapse of coral rock from the escarpment took place one day in 1900 over the Boscobelle area in the north-east corner of Barbados and its remains, covering nearly a square mile of ground, form an imposing sight when viewed from the edge of the cliff above. An old negro who was there at the time told me that the fall was rather of a gradually sliding nature than a violent collapse and no lives were lost.

It is clear that the coral rock covering must recently have extended higher and further to the east over the Scotland area. Several of the larger gullies for instance one locally called Welchman's Hall gully that lies just south of Mt. Misery (1,053 feet) and near Canefield opens directly on to the escarpment overlooking the Scotland district but slopes away from it to the south-west. It has evidently been beheaded by the breaking away of the coral rock along the escarpment. This gully, now nearly dry, for some distance cuts through the coral rock and its flat bottom evidently lies on the Oceanics though these are hidden by a layer of clay.

I am indebted to my friend Mr. W. C. Clarke of Hastings, Barbados for drawing my attention to the Boscobelle landslide and to several other features of the island. Mr. Clarke has an unrivalled knowledge of the various estates in Barbados.

This pitch or tilt together with the curving outline of the ridge of uplift are features of considerable significance in connection with the possibility that we have here an example of mountain-building process in embryo[1] rather than an uplift due to intrusion of a laccolith of igneous material below the surface as Harrison and Jukes-Browne suggest (p. 38).

When one stands on the edge of the escarpment at Hackelston's cliff one can see on the coast at Bathsheba nearly 1,000 feet below, masses of coral rock most of which have fallen from the cliffs. However some of the larger horizontally lying masses of coral rock at Bathsheba may be in situ. If this is the case the oblique tilt of the higher part of the island becomes very apparent, but I could not find any undisturbed junction of the coral rock and Oceanics there.

Messrs. Harrison and Jukes-Browne seem to regard the relics of coral rock that strew the slopes of the Scotland area in many places as masses still in situ where they grew, but to me they all appear to be fragments slipped down from the escarpment.

The terraces of coral rock when viewed in profile rise in fairly regular series of platforms, slopes, rounded ridges, and cliffs from sea-level. At heights of about 400 feet and more they form rugged and precipitous slopes as though fault scarping as well as coastal erosion, rather than coral growth on submarine platforms had been responsible for forming them. Definite evidence of fault scarps is difficult to obtain however. At levels above 500 feet the coral rock becomes more rugged and ravined and is dissolved into sink holes, "cock-pits" etc., while at highest levels it is seen in all stages of cracking up, collapse, and breaking away down the slope.

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[1] Compare Brouwer, *Geol. of Netherlands East Indies*, 1925, 49.

A noticeable feature of the lower terraces is that they are often higher on the outer or seaward edge and slope down inland towards the next cliff or rise. This might be explained as a lagoon inside the reef but I think it is due to tectonic causes and that repeated lateral pressure from the south and west has further warped up the outer edges of the terraces. The terraces are not perfectly regular but often seem to merge one into another ; a detailed mapping of the contours of the island might throw further light on their origin. At some places, for instance in a deep road cutting near Colleton about 4 miles south of the north point of the island near the west coast one sees evidence of internal movements in the low level coral rock in the form of planes of fracture or sliding at an angle of about 45 degrees to the north-west, apparently the result of uplift or thrust.

The extreme north end of Barbados offers some interesting features. It consists of an undulating surface which slopes gently towards the sea. At about 2 miles south of the north point the first scarp offers a line of abrupt cliffs that curves from Mt. Poyer towards Pico Teneriffe. The latter is an isolated pointed mass of old weathered coral rock looking like a miniature Matterhorn resting on Oceanic chalks which are here at least 150 feet thick.

At some late period this northern end of the island seems to have been scoured by the sea, a process which has worn the coral rock very thin in places and has exposed the underlying Scotland sandstones at Spring Hall and Chance Hall. At the foot of the first cliff there are several detached masses of coral rock that have been undercut by the waves and form mushroom-like fragments. The cliffs a few yards behind them are perpendicular and smooth and about 100 feet high and contain caves apparently cut out by the sea. This apparently wave-cut platform now stands high and dry at an elevation of 60–100 feet above present sea-level, a result either of a rise of the land or lowering of the sea in comparatively recent times. See the view (Pl. III, Fig. 3).

Fringing reefs grow around a great part though by no means all around the island at the present day. Perhaps one would be wrong in attributing any great rock-building activities to these existing reefs. Here as in most coral islands, unless special borings have been put down, the difficulty is to know how deep the coral rock goes down below sea-level. No very reliable data seem to be obtainable as wells are generally only sunk to a level where the sea comes in and renders the water brackish.

With the possible exception of certain late-looking veneers along parts of the west and south coast I imagine that the great and uniform coral capping of Barbados was formed at some fairly early period over an extensive submarine platform, and not by a succession of fringing coastal reefs. This capping which doubtless once covered the whole island was completely formed before the process of uplift commenced. It follows therefore that the high reefs are not necessarily older than those at medium or low levels. The very base of the coral rock at high elevations where it merges down into beds of the Bissex Hill type or at Consett Point where the hard older-looking beds noticed by Professor Spencer occur may contain fossils of older aspect. *Pectens* having a pre-Pleistocene aspect were found in the lower coral rock near Consett Point.

Otherwise, bad as is the condition of the fossils at the highest levels (800–1,000 feet), I cannot find that the mollusca differ from those at moderate elevation (200–800 feet) or from those at low levels (sea-level—200 feet). Several of the coral rock mollusca at low elevations differ perceptibly from the present-day living forms, a feature that goes to show that the fauna even at low levels is by no means quite recent.

The coral rock may have accumulated with comparative rapidity; at Sandy Lane 5 miles north of Bridgetown not far above present sea-level a large branching coral, some form of Madrepore, about 7 feet high can be seen with the interstices filled with well-preserved remains of all sorts, mollusca, crustacean claws, etc. Equally large coral masses occur at high levels but are much dissolved.

Some of the coral rock even at high levels consists of great thicknesses of comminuted coral sand often with current bedding simulating dipping. This material is locally called " marl " and is much quarried for building purposes.

Amphistegina lessoni [1] D'Orb. is generally considered a fairly deep water foraminiferon. I found it in vast numbers at several places at the base of the coral rock, for about 9 miles along the escarpment at high levels where it resembles masses of white lentils; but I did not find it at the base of the coral rock at low levels. It would seem as though the highest parts of the island at the present day may have been the deepest or most depressed at the beginning of coral rock times.

The occurrence of peculiar beds overlying the typical Oceanics at Bissex Hill about the centre of the Scotland area which seem to indicate a shallowing of Oceanic conditions and a passage to coral rock formation may also point to the same conclusion. Mr. F. Chapman recognized *Amphistegina lessoni* in a bed at the base of the coral rock in the Bowmanston Waterworks shaft, where also I collected it lately.

During the Pleistocene period the general lowering of the surface

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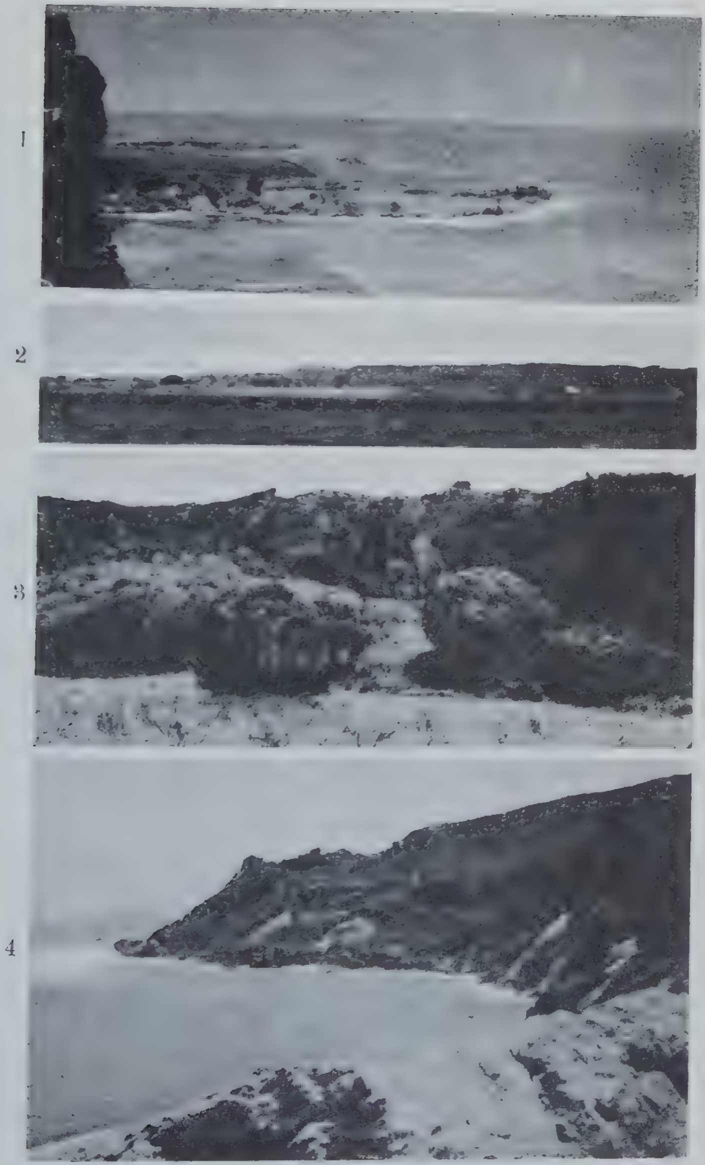
[1] *Amphistegina lessoni* d'Orb. is recorded from 23 fathoms in the Seychelle Islands; from 12 fathoms off Fiji; 16–25 fathoms off Admiralty Islands by the Challenger Expedition. According to Brady it occurs from 300–400 fathoms, but is commonest on bottoms of less than 30 fathoms. I am indebted to Dr. H. Dighton Thomas of the British Museum for assisting my identification of this foraminiferon that occurs in such quantities in Barbados.

PLATE III.



C.T.T. photo.

VIEWS OF BARBADOS, CORAL ROCK AND OCEANIC SERIES.

[*To face p. 24.*

of the oceans in tropical areas owing to the binding up of water in the ice-sheets has been variously estimated, but a depression of roughly 150–180 feet seems to be generally agreed upon. To this one should apparently add a further withdrawal of about 40 feet due to the attraction of water in the vicinity of the great ice sheets. This factor has in other regions been adduced to account for the submergence of the great Sunda or Sahul shelf in the region of the Malay archipelago.[1]

However tempted one may feel to invoke the Glacial Control theory of Daly to account for the 200 or 250 feet of coral capping on Barbados, one may question whether such a considerable geological process as the formation and subsequent uplift of this coral capping can be fitted into the period since the end of glaciation in the north. Some of the terraces of Barbados may however have been cut during temporary rises of the sea-level during glacial or post-glacial times.

SECTIONS OF THE BARBADOS CORAL ROCK.

Ragged Point. (Fig. 3.)

At and around Ragged Point lighthouse on the south-east corner of the island a section of the base of the coral rock rests on the eroded edges of the Scotland beds, the Oceanics are missing here evidently through erosion before deposition of the coral rock.

	Thickness in feet.
Old-looking altered coral masses and much dissolved coral rock which is thin and disappears near the lighthouse. The junction slopes rapidly down to the south-east and a quarter of a mile away on the south side of Spring Bay the coral rock occupies the whole cliff 80–100 feet high. Fossils: *Astralium*; *Conus princeps*; *Fissurella barbadensis*; the latter found near the base of the coral rock . . .	1–100
Unconformity.	
Thick sandstones, grits and clays dipping north-west; low in the Scotland series	over 150

Around and behind the lighthouse is a platform of coastal erosion, which slopes gently westwards towards the interior of the island before the next bench or cliff of coral rock is reached. Both the exposed Scotland sandstones and the coral rock have been levelled by scouring so the formation of the platform is a much later event than the actual growth of the coral rock. Here also the seaward edge of the platform is higher than the inland part, due as I imagine to later warping up of the edges.

No trace of the *Amphistegina* bed of the higher levels was seen here, and as *Fissurella barbadensis* is a keyhole limpet that sticks

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[1] Brouwer, *Geol. of Netherlands East Indies*. 1925, 9.

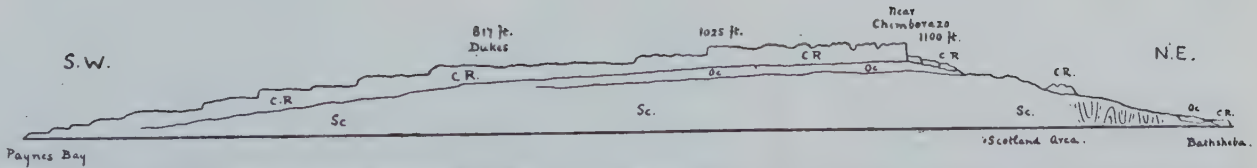

FIG. 2.—Ideal section across Barbados from near Payne's Bay to Bathsheba, about 8½ miles, to show the differential uplift and the rising terraces of Coral Rock (C.R.), underlain by Oceanics (Oc.) and Scotland Beds (Sc.). The masses of Coral Rock and Oceanics lying on the Scotland area are displaced, though some of the coral rock on the shore at Bathsheba may be in place. Vertical scale exaggerated.

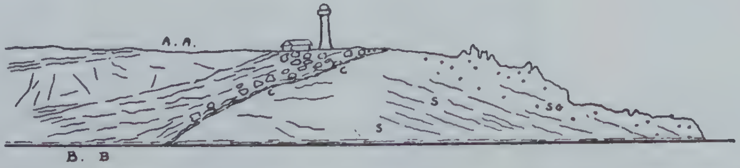

FIG. 3.—Sketch of cliff section at Ragged Point, Barbados, showing base of the Coral Rock resting on Scotland Beds, the Oceanics missing. Height of cliff about 70 feet; vertical scale exaggerated. The lighthouse stands on a surface of marine scouring developed previous to the last uprise. A.A., massive Coral Rock much jointed; B.B., bedded Coral Rock; C.C., broken up Scotland shales, the base of the coral rock enclosing masses of Scotland sandstone; S.S., Scotland shales; S.G., Scotland grits and sandstones.

on rocks at the present day one may conclude that at the commencement of coral rock times the Ragged Point area was a shallow water one.

Consett Point and Neighbourhood.

In a railway cutting here a bedded calcareous sand rock passes up without any definite break into a hard massive limestone containing corals and *Livonia pica.* The sand rock contains a few *Pectens* and echinoderm fragments. Three species of *Pecten* collected here differ from the living species and though difficult to identify seem to be pre-Pleistocene forms.

In the grounds of a farmhouse called Fortescue about a mile south of Consett Point an isolated rounded mass of greyish white hard limestone full of a Lithothamnion-like structure occurs. I collected a number of small fossils here, chiefly bivalves. The relation of this limestone to the coral rock in the higher ground to the west could not be seen but it is evidently rather low in the series here. The fossils are young or poorly preserved specimens of the following species and seem to be living forms :—

Turritella cf. *exoleta* Linn ; *Arca imbricata* ? Brug. ; *Lima* cf. *multicostata* Sow. ; *Cardium medium* ? Linn ; *Laevicardium serratum* Linn ; *Lucina imbricatula* ? C. B. Ad. ; *Lucina columbella* Lam. ; *Divaricella quadrisulcata* D'Orb.

This area is the district of Barbados where Spencer claims to have found limestones of the Antigua type of Oligocene age. He gives a diagram of the section calling it a " section near Ragged Point ".[1] J. B. Harrison takes the matter up in his paper and corrects this mistake.[2] Spencer claimed the lower bedded limestones at Ragged Point, really Consett Point, to be older, on account of their dip 15–20 degrees south-east and the supposition that the beds above are unconformable. They certainly dip but it looked to me like current bedding and they merge up gradually into the massive coral rock above.

Gay's Cove, north-east of Barbados. (Pl. III, Figs. 1 and 4.)

Along the coastal cliffs north and north-west of Gay's Cove the coral rock is often very thin, in places only a veneer. It rests unconformably on an irregular surface of Oceanic chalk which dips at 45 degrees about east. Small faults occur in the Oceanics and affect the base of the coral rock. The latter is mixed up with Oceanic marl and locally consists of broken coral masses embedded in derived chalk ; in other places it forms beds of branching and massive corals and the fossils are well preserved but few in species. The thinly bedded basal coral rock here passes under the massive coral rock at the escarpment to the south-west. At the south end of Gay's Cove towards Pico Teneriffe the following section was observed at the base of the coral rock.

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[1] *Quart. Jour. Geol. Soc.*, lviii, 1902, 358.

[2] *Quart. Jour. Geol. Soc.*, lxiii, 1907, 320.

	Thickness in feet.
Hard dense coral rock	20
A bed of rolled pebbles of hard limestone and small comminuted fragments and quartz grains. This limestone contains traces of corals and looks like some of the limestones that occur in the Bissex Hill beds. No trace of *Amphistegina* was observed here	1
Unconformity.	
White and cream-coloured Oceanic chalks	100

About 2 miles to the north-west, at River Bay the coral rock is about 60 feet thick in the sea cliffs and at places it is tilted and faulted. At the Animal Flower Cave beds of large rolled masses are jumbled together and interbedded with more regularly stratified coral rock as though there had been prolonged rolling on a submarine shelf.

Chimborazo, near the High Escarpment.

Section in a small cliff on which the farmstead of Chimborazo stands, the elevation is about 1,090 feet.

	Thickness in feet.
Coral rock hard and indurated the fossils obscured, but made up of coral remains with *Amphistegina* in places, largely changed into a compact calcitic mass	30
Bed almost entirely made up of *Amphistegina lessoni*	5
Bed with a white matrix containing *Amphistegina*, Cidaris plates, echinoid spines, badly preserved simple corals and other coralline structures and sharks' teeth; clay ironstone and manganiferous nodules and just above the junction angular fragments of the underlying Oceanic chalks	2
Unconformity.	
Grey and red clays and globigerina chalks of the Oceanic series	20 seen

Farley Hill, on the Escarpment.

A section of the base of the coral rock at high level 763 feet is seen in a road cutting just north of the old mansion of Farley Hill on the edge of the escarpment overlooking the Scotland area.

	Thickness in feet.
Coral rock with large massive corals, the mollusca dissolved, occurring only as broken casts	15
Coral rock much broken and dissolved, occasional *Ostrea frons* at the base	10
Dense white limestone with a few specimens of *Amphistegina* near the base	1
Unconformity.	
Oceanic globigerina chalks	30 seen

Canefield, near Mt. Misery.

Here at about 1,000 feet elevation a quarry a short distance back from the escarpment yields recognizable fossils; large gasteropoda, *Strombus gigas* (?); *Livonia pica*, very large specimens; *Spondylus americanus*, etc.

Gun Hill.

About 5 miles north-east of Bridgetown at 680 feet elevation the coral rock is exposed in a quarry, it is here very pure and is burned for lime used in sugar refining. It is composed of many corals some of them much dissolved and very light in weight, a few of the mollusca still retain the shell and also colour markings. In other parts the rock is reduced to a mush and the fissures and cracks lined with calcite, and elsewhere there are bands of very heavy and dense rock. Fossils are plentiful.

Belle Waterworks.

These are situated about 140 feet above sea-level and the coral rock goes down to at least 140 feet, but whether the base was reached is not known.

Bowmanston Waterworks.

At about 600 feet above sea-level a well shaft has been sunk here through 240 or 250 feet of coral rock to near its base in order to reach a stream of water which flows in a completely underground gully to the south-west, no doubt down the dip slope on the surface of the Oceanic beds. Near the base the coral rock is hard and well bedded and contains clay ironstone nodules, *Amphisteginae*, and debris apparently of Halimeda. On descending the shaft one sees much dissolved coral rock with large massive corals here and there but few recognizable mollusca.

I am indebted to Major G. E. Peck, M.C., M.I.C.E., for facilities for descending the Bowmanston shaft at the bottom of which one can walk for miles in either direction nearly up to one's neck in water, and for information regarding the waterworks borings.

Erdiston.

Here by permission of the owner of the mansion, Mr. Sam Manning, visitors are enabled to see a series of caves which appear however to be old marl excavations. They are on the first considerable rise above sea-level at about 150 feet, and show bedded coral rock almost entirely made up of broken branching corals mixed with shells. The beds dip at 40–45 degrees east-north-east that is towards the higher parts of the island, a result apparently of warping up of the outer edge of the shelf. Many fossils are preserved in the house—*Cassis flammea; Spondylus;* large *Dactyli, Chione multicostata* and other species.

Rouen Village.

In yellow marly rock in road cuttings at and near Rouen a specially fine series of coral rock fossils can be collected at about 150 feet above sea-level. The mollusca which have the shell well preserved include *Chione multicostata,* a Pacific form; *Chione paphia; Murex toupiollei,* etc.

RAISED CORAL REEFS OF OTHER ISLANDS (WEST INDIES).

Professor L. Rutten writes to me "the highest point on Curaçao where coral rock occurs is Mt. Tafelberg on the west of the island, 230 metres. It is certain that the coral rock has covered by far the greatest part of the island probably Mt. Christoffel and environs excepted. It is very difficult to say whether the rocks are Plio-pleistocene or Pleistocene; the palaeontological evidence however points to Pleistocene *vide* Lorié, molluscs; Vaughan, corals". Later he writes, "The older, certainly Quaternary limestone has been distinctly folded or domed; afterwards the island has been elevated or the sea-level has subsided, Daly effect?; during this time the deep valleys have been formed which later became land-locked bays. In later time the sea-level has risen, possibly connected with a differential movement of the land indicated by the fact that in the north-west the bays are generally less drowned than in the south-east. In a still later time the sea-level has risen still more and the young coral limestones which encircle almost the whole island at about 6 metres above sea-level have grown. A last movement was a subsidence of the sea-level of about 6 metres, bringing the young limestones to their actual niveau. On these young limestones (Asiento formation of Molengraaff) the petroleum establishment has been built."

Further information about Curaçao is given by Dr. G. J. H. Molengraaff[1]: "The Pleistocene strata dip at an angle of 20° to the south along the south coast, while these layers along the north coast only show a slight dip to the north. The Pleistocene doming is therefore asymmetrical."

From what I saw in Curaçao the coral rock looks older and harder and much more denuded away than that of Barbados.

Aruba and Bonaire also have in part reef caps.

Trinidad has no raised coral rocks. More than 800 fathoms depth of sea separates Barbados from Tobago. The northern higher part of Tobago consists of schists, the southern half carries late Tertiary beds overlain by coral rock which rises in terraces.

On St. Lucia I saw no raised reefs but in the Botanical Gardens at Castries a bed full of mollusca apparently of holocene date. Dominica has coral marls at 50 feet elevation, which have been discussed by Professor Spencer and Dr. K. W. Earle.

All of Marie Galante consists of recent limestone. Antigua and Barbuda have present-day fringing coastal reefs but no raised coral reefs. Dr. T. W. Vaughan[2] says he did not notice any definite elevated terraces on Anguilla and remarks that the beds of Anguilla are of Burdigalian or Aquitanian age. W. P. Woodring[3] says that no Tertiary beds are found on the northern Virgin Islands but that

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[1] *Leidsche Geolog. Mededeelingen*, Deel v, Nov., 1931, 683.

[2] *Journ. Wash. Acad. Sciences*, xvi, No. 13, 358.

[3] *Proc. of Third Pan-Pacific Science Congress*, Tokyo, 1926, 418.

Anegada a low reef-capped flat island consisting of Quaternary limestone at the north-east end of the virgin bank is the only island in this group capped with recent limestone. He also states that in the north-west peninsula of Haiti a series of reef caps so far as is known of Quaternary age arches over the crest of a Miocene anticline at an altitude of more than 400 metres above sea-level.

On the island of Tortugas off the north coast of Haiti I have observed from the sea very perfect benches. In Jamaica I saw raised coral rock with recent-looking fossils forming a fringe of only 25 feet or so elevation, though older coral rock with obscured fossils may occur rather higher. The Cayman islands are partly reef capped.

On the south coast of Oriente province Cuba the benches have a maximum altitude of almost 200 metres above sea-level.

THE DUTCH EAST INDIES.

Certain islands in the East Indies show coral reefs still more elevated than on Barbados. Professor G. A. F. Molengraaff[1] says regarding the East Indian islands "I believe, that generally speaking it may be accepted, that where a deep sea chart shows a complicated topography the adjoining coasts must show signs of upheaval, in tropical regions as a rule, elevated coral reefs, and where this is not the case one must expect no evidence of importance in favour of the upheaval of the adjoining coast."

Dr. G. J. H. Molengraaff in a letter to me in June, 1929, says "I found in the year 1911 the Pleistocene coral reefs in the island of Timor raised to a height of 1,200 metres (= 3,945 feet) at the Gempol-Rand near Kapan, Dutch Timor. At some places they are raised to a higher level still.

Professor A. H. Brouwer[2] gives a diagram illustrating the asymmetrical profile of several coral islands which do not rise in a vertical plane but have been pushed up obliquely with the result that the oldest reef caps are not always found at the highest elevations. "The outer row of islands about the Banda Sea has accommodated itself to a considerable degree to the shape of its 'vorland' the Sahul shelf. The Tenimber and Kei islands have an outlying position in the row and both are situated opposite depressions in the Sahul shelf. The progressing geanticline has met with less resistance opposite these depressions, hence the outlying position of these islands." The islands Rotti and Jamdena illustrate this point. Reading about these islands first gave me the clue to the explanation of similar abnormalities I had observed in Barbados.

Brouwer goes on to say (p. 70) "In the Timor arc the elevated reefs occur at an elevation of 1,300 metres in the central parts of the island of Timor, while to the east and west the height gradually decreases; on Rotti to the west the highest reefs are found at 470 metres and on Savu still farther to the west they are at 300 metres. On the islands farther to the east the height decreases to 140 metres on Letti, to 20 metres on Lakor while on Luang no elevated reefs are found."

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[1] "On recent crustal movements in the Island of Timor, etc.": *Konikl. Akad. van Wetensch. te Amsterdam*, September, 1912, 11.

[2] *The Geology of the Netherlands East Indies:* Univ. of Michigan Studies, Scientific Series, iii, 1925, 60.

PALAEONTOLOGY OF THE BARBADOS CORAL ROCK.

At different times for some years I have searched for evidence whether the coral rock at high levels might yield a fauna different from that in the rock at lower levels. The wretched state of preservation of fossils in the high-level rock which is generally reduced by solution and recrystallization to a mush with only casts of fossils made the search rather discouraging. However at Chimborazo, Canefield, Farley Hill, Cherry Tree Hill and other places along the high escarpment at elevations of 900–1,000 feet I have obtained specimens or moulds from which to make impressions.

One finds that the mollusca in the high-level rock do not seem to differ from those at lower levels and that if any of the fossil mollusca differ from the living species they can be collected in the lower as well as the higher reefs.

Sir R. Schomburgk in 1847 pointed out that the coral limestone of Barbados had been elevated during the period of existing shells, but that in many cases the specimens are of larger size than in the living fauna or that they occur more commonly or more rarely in the coral rock than on the coast at the present day.

In later papers the coral rock mollusca have generally been listed as identical with the living forms. The large series in the British Museum collected by the Right Rev. Bishop Mitchinson, were from low levels near Bridgetown and are listed in Professor Gregory's paper.

Professor J. W. Gregory,[1] though I believe he never visited Barbados, goes deeply into the study of the corals from the raised reefs and remarks on the difference between the corals of the raised rock, in fact in the low level rock and those still living in the adjacent seas. "Of the 31 species of corals found in the raised reefs of Barbados 4 species and 3 genera are not known to occur at the present time in the West Indian seas." "In the second place two of the extinct species and one of the genera new to the West Indian fauna occur not in the high level but in the low level reefs, where they are associated with a molluscan fauna of late Pleistocene age." He also gives a list of over 140 species of mollusca, identified by Mr. E. A. Smith from the low level reefs near Bridgetown. These are all recent species but a few are quoted as occurring at Panama or in the Indo-Pacific region.

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[1] *Quart. Jour. Geol. Soc.*, li, 1895, 286.

The following list includes the more conspicuous mollusca I collected in the Barbados coral rock. Where not otherwise stated they agree with the living forms and occur in the low level rock. Some of them differ perceptibly from the recent shells or from those I have been able to obtain or examine ; others are very like forms found in the raised limestones of Brimstone Hill, St. Kitts and may be of Pliocene aspect. A few species are Panama forms or more like the Panama analogues.

Lamellibranchiata.

Ostrea cf. *Frons*. Linn.

A left valve from Canefield 1,000 feet, with the size and outline of this species but the shell much less strongly plicated ; not unlike but larger than *O.* (*Lopha*) *guppyi* Woodring from the Bowden beds. Valves resembling this oyster occur at the base of the coral rock at Chimborazo 1,000 feet, and at Rouen 150 feet.

Ostrea folium Linn.
Spondylus ictericus Reeve.
Spondylus americanus Lamk. var.

A large valve in a quarry at Canefield 1,000 feet ; also at Erdiston 100 feet.

Plicatula ramosa Lam.

Common around Rouen village 150 feet.

Lima (*Ctenoides*) *scabra* Born.

At Chimborazo and other places 1,000 feet and at lower levels.

Lima cf. *multicostata* Sow.
Pecten (*Nodipecten*) sp.

Sir J. B. Harrison wrote me in 1925, " while in Barbados I obtained from the basal coral rock a very fine specimen of *Pecten* (*Nodipecten*) which is much larger than *Pecten nodosus* the largest living West Indian species and differs from it in other features. It resembles *Pecten pittieri* Dall described from beds said to be of Pliocene age at Port Limon, Costa Rica." The actual locality was not stated.

Pecten (*Vola*) *zic-zac* Linn.

Rare at low levels, resembling the living form.

Pecten ornatus Lam.

At Canefield 1,000 feet and low levels.

Pecten modestus Mörch (=*fucatus* Reeve).
Pecten (*Chlamys*) cf. *nucleus* Born.

A flattish valve at Canefield 1,000 feet. A small very arched *Pecten* of the type of *P. nucleus* or *P. circularis* Sow. at Consett Point ; it is 15 mm. in diameter and has eighteen rounded ribs and deep interspaces. It is very like a common form in the Manchioneal beds in Jamaica which is comparable with *P. barretti* Woodring or *P. ameleus* Woodring from the Bowden beds. Another arched *Pecten* 32 mm. in size and almost circular in outline resembles the living *P. gibbus* or *P. nucleus* but has more numerous ribs about twenty-five in number and wider interspaces. The living *P. nucleus* has about twenty-one ribs with wider interspaces. These *Pectens* are very difficult to identify specifically but some of them from the base of the coral rock seem to be Pliocene forms.

Pecten (*Chlamys*) sp. (Pl. IV, Fig. 2.)

A right valve with a general resemblance to *P. irradians* Lam. or *P. concentricus* Say, but the ribs about seventeen in number are more inflated near the beak, relatively broader and widen more rapidly. The margin of the shell is more expanded anteriorly, the ribs are rounded and crossed by fine growth lamellae ; the ribs and interspaces are plain without secondary riblets. Height 37 mm., width 40 mm. Lower beds at Consett Point. The recent *P. irradians* has about twenty-one ribs.

Lithodomus antillarum D'Orb.

Common at Gun Hill 600 feet.

Lithodomus cinnamominus Chem.
Perna alata Gmelin.
Perna bicolor C. B. Ad.
Pinna sp.

Rouen Village.

Arca imbricata Brug.

Fine specimens at Rouen Village.

Arca squamosa Linn. = *domingensis* Lam.
Barbatia cf. *decussata* Sow.

Barbatia is common at low levels but often much distorted and variable in shape from growing on coral reefs. The ornament varies in coarseness but varieties seem to grade into one another. Some resemble the above species or the recent *B. fusca* Brug. or *B. candida* Chem. ; others recall the Bowden fossil *B. inusitata* Woodring but have a narrower hinge area.

Scapharca cf. *Deshayesi* Hanl. var. 2. (Pl. IV, Fig. 1.)

Several valves of an Arca of the *Deshayesi* type were collected at Rouen. The anterior twenty radiating ribs are rather narrow and sharp and the grooves between them rather flat and wide and each rib carries a very distinct groove. Ribs 20–26 are wider and carry two rather fainter grooves. The area is rather broad with slightly wavy incisions. They are exactly like one of the three or four varieties of this shell that occur in the raised limestones at Brimstone Hill, St. Kitts.[1] Recent specimens of *A. deshayesi* picked up on

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[1] Geol. Mag., LXIX, 1932, 252, Pl. XV, Fig. 10.

St. Kitts have the radial ribs generally rounded and only the first six of them carry a faint groove.

Pectunculus (*Glycimeris*) *pennaceus* Lam.

Common at high levels.

Pectunculus pallium Reeve.

Cardium (*Laevicardium*) *serratum* Linn.

Gun Hill and at low levels.

Cardium (*Fragum*) *medium* Linn.

Cardium (*Fragum*) *aff. graniferum* Brod.

A small *Cardium* very plentiful in the coral rock ; it also resembles *C. sambaicum* Maury from Haitian beds and *C.* (*Fragum*) *burnsii* Dall from the Alum Bluff group of Florida. *C. graniferum* is a Panama shell and has fewer ribs. This small *Cardium* also occurs recent on the West Indian beaches. Gun Hill and at low levels.

Chama macrophylla Chem.

Chama ruderalis Lam.

Basterotia quadrata Hinds.

Rare at low levels.

Cytherea (*Dione*) *albida* Gmel.

Basal coral rock at Gay's Cove, and other localities.

Chione paphia Linn. cf. var. *Christopheri* Trechm. (Pl. IV, Fig. 3.)

Fine specimens occur at Rouen Village : they are larger and more drawn out and pointed anteriorly and posteriorly and have more irregular ribbing than most of the recent specimens which conform much more to a constant type. The coral rock specimens resemble those that occur at Brimstone Hill, St. Kitts but are more pointed in front and the anterior end is turned upwards.

Chione (*Omphaloclathrum*) *cancellata* Linn. (Pl. IV, Fig. 7.)

Examples of this species show much variation, some from Rouen have widely spaced frilled ribs, or ribs widely spaced when young but crowded together later ; others from the basal coral rock at Gay's Cove are more arched and have irregularly spaced ribs. One specimen from Gay's Cove (Fig. 7) is very similar to *Chione woodwardi* Guppy a Bowden species as figured by Woodring,[1] it has the same frilled ribs but the lower posterior margin is less angulated. I did not see in the Barbados coral rock a form that occurs at Brimstone Hill, St. Kitts which I called *Chione cancellata* var. *Christopheri*.

At high levels as casts ; common at Rouen Village.

Chione multicostata Sow. var. (Pl. IV, Fig. 6.)

This large species is everywhere so far as I can ascertain listed as an Indo-Pacific or Panama shell. It occurs at and around Rouen Village, 150 feet ; there are three specimens in the British Museum from low levels near Bridgetown and I have it from Erdiston at about 150 feet altitude. It seems rather shorter than the Panama specimens.

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[1] *Miocene Moll. from Bowden,* 1925, 160, pl. xxii, figs. 1–3.

Anomalocardia braziliana Gmel.
Dosinidia concentrica Gmel.

Fine examples occur at Rouen and are comparable with recent shells from Florida and Brazil but the fossil is rather less inflated and has more numerous, closer set and less regular concentric ribs than the recent shell. The ribbing on the fossil is more like that on the living Panama analogue *P. discus* Reeve.

Cyclina near *C. subquadrata* Hanley. (Pl. IV, Fig. 4.)

At Rouen a fossil occurs like this living Panama form but rather smaller and having the valves more evenly rounded less arched and more circular in outline. The living Pacific species has a broad ridge on the posterior surface which causes the lower posterior margin to be rather broadly prolonged.

Petricola lapicidum Chem.

Casts of shells and burrows at Edgecliff 900 feet, on the escarpment and more rarely at low levels.

Diplodonta rotundata Mont.
Asaphis defloratus Linn.
Philis (*Cryptodon*) *chrysostoma* Meuschen.

Common at Gay's Cove, Rouen Village and other places.

Lucina pennsylvanica Linn.

Chimborazo 1,000 feet ; Gun Hill 600 feet and low levels.

Lucina columbella Lam.

Small specimens in hard old-looking coral rock near Consett Point.

Lucina (*Phacoides*) *jamaicensis* Spengl.
Codakia imbricatula C. B. Ad.
Codakia orbicularis Linn. var. (Pl. IV, Fig. 5.)

A specimen from 40 feet altitude on the Savannah near Bridgetown is more nearly circular in outline than the recent shell which is wider than high. It has straighter and less wavy ribs, more numerous growth lines and a more reticulated surface ornamentation which becomes almost prickly near the posterior margin. It is very like a variety that occurs at Brimstone Hill, St. Kitts. The Indo-Pacific analogue is generally called *C. tigerina* Linn = *C. exasperata* Reeve.

Codakia costata D'Orb.
Divaricella quadrisulcata D'Orb.

Chimborazo 1,000 feet and lower levels

Tellina (*Arcopagia*) *fausta* Pult.
Tellina (*Metis*) cf. *ephippium* Spengl.
Tellina (*Tellinella*) *interrupta* Sol.
Tellina (*Tellinella*) *decora* Say.
Tellina (*Musculus*) *radiata* Linn.

Gasteropoda.

Bulla cf. *vendryesiana* Guppy. (Pl. IV, Figs. 15, 16 and 17.)

Fossil *Bullas* of this type are common in the coral rock around Hastings and in the basal coral rock at Gay's Cove. They seem to conform well to one type and are very like specimens from Brimstone Hill, St. Kitts. They are solid, smooth and glossy with well-marked growth interruptions. The sunken umbilicus is small often merely like a pin-prick while in the living shells it is generally open and deep. The posterior lip in the fossil is deeply cut out near the umbilicus and its margin extends well behind making the aperture longer than the shell, while in the living form the margin is less raised above the umbilicus. The callosity of the inner lip in the fossil is thicker and more everted and the margin of the inner lip is more suddenly cut away to the left hand, or the aperture expands more anteriorly than in the living form.

These features are not absolutely constant, occasionally one finds a fossil with a wide and deep umbilicus but on comparing a number of the coral rock *Bullas* with the recent forms *B. striata* Brug. or *B. maculosa* Mart. (Fig. 18) one sees an appreciable distinction which puts them closer to the fossil *B. vendryesiana* of the Bowden beds than to the living shells. In the latter the shell is often variable in thickness whereas the coral rock form is thick and solid. I consider this a useful shell for demonstrating that even the lowest coral rock is by no means quite recent.

Bulla solida A. Ad.

Erdiston 150 feet.

Conus (*Hermes*) *granulatus* Linn.

Low levels near Bridgetown it seems to have stronger more regular and straighter ribs than the recent shell.

Conus verrucosus Hwass.
Conus daucus Hwass.
Conus mus Hwass.
Conus testudinarius Mart.
Conus cf. *princeps* Linn.

In old-looking coral rock south of Ragged Point, a *Conus* resembling this Panama species.

Drillia near *cretata* Smith.
Drillia sp.

Cancellaria reticulata Linn.
Oliva litterata Lam.

A cast at Cherry Tree Hill 800 feet, rare at low levels.

Olivella jaspidea Gmel.
Marginella (*Volvaria*) *avena* Val.
Mitra granulosa Lam.
Mitra barbadensis Gmel.
Mitra (*Pusia*) cf. *ansulata* Sow.
Voluta musica Linn. (Pl. IV, Fig. 10.)

In a quarry near the Marine Hotel, Hastings, at about 20 feet altitude a large specimen with deeper suture and much stronger nodes than a recent example of corresponding size.

Leucozonia (*Latirus*) *cingulifera* Lam.

Common at low levels around Hastings.

Cynodonta muricata Born. = *pugillaris* Lam.
Melongena melongena Linn.

Rouen Village; fossil specimens have smaller spines than most of the recent examples but I have seen the latter also with very few spines, so the feature may not be of much significance. Casts of large gasteropods at Canefield 1,000 feet may belong to this species.

Phos (*Strongylocera*) *pallidus* Powis.

At low levels near Hastings and a cast at Edgecliff 900 feet. The ornamentation on the fossil specimens varies but they seem to belong to this species.

Tritonidea (*Pollia*) *coromandeliana* Linn.

Common at low levels near Hastings.

Latirus spadiceus Reeve.
Caducifer tesselatus Reeve.
Pisania pusio Linn.
Nassa ambigua Mont.
Columbella mercatoria Linn.

A cast at Farley Hill, and common at low levels.

Murex toupiollei Born.

Fine specimens at Rouen Village.

Murex (*Haustellum*) *messorius* Sow. (Pl. IV, Fig. 14.)

Low level coral rock along the west coast.

Ocinebra cf. *Adamsi* Kobelt = *alabastrum* A. Ad.
Thais deltoidea Lam.
Ricinula (*Sistrum*) *nodulosa* C. B. Ad.
Coralliophila near *galea* Chem. or *abbreviata* Lam.

Specimens up to 50 mm. long occur at low levels on the western side and I found one more fossilized at 150 feet altitude a mile inland from Hastings, and a cast at Gun Hill 600 feet. The shells are variable as regards the angulation of the body whorl and elevation of spire and are similar but evidently not identical with the Indo-Pacific form *C. galea.*

Coralliophila nivea C. B. Ad.

Coralliophila barbadensis sp. nov. (Pl. IV, Figs. 12 and 13.)

A small thick compact shell up to 22 mm. long occurs at low levels. The umbilicus is very small, sutures shallow, whorls rounded, longitudinal ribs well marked, spiral ridges strong and foliaceous, aperture oval. At low levels on the western side of Barbados.

Ranularia (*Gutturnium*) *tuberosa* Lam. = *R. antillarum* D'Orb.

Common at Rouen Village and a cast near Chimborazo 1,000 feet. Very similar to Indian Ocean specimens; it is recorded by Dall from Porto Rico.

Ranella (*Bursa*) *thomae* D'Orb.
Ranella (*Bursa*) *affinis* Linn. var. or *R. cubaniana* D'Orb.
Triton tritonis Linn.
Colubraria testacea Mörch.
Lampusia pilearis Lam. var.
Cassis flammea Linn.
Cassis inflata Shaw.
Dolium perdix Linn.
Cypraea cf. *cinerea* Gmel. and var. *Clara* Gask.

At 1,000 feet and lower levels.

Cypraea exanthema Linn.
Cypraea (*Luponia*) cf. *spurca* Linn.

Common at low levels.

Trivia nivea Gray or *vitrea* Gask.
Cyphoma (*Ultimus*) *gibbosa* Linn.
Strombus pugilis Linn. var. (Pl. IV, Fig. 11.)

Coral rock specimens are generally thick-shelled with few and low spines on the body whorl, but a series of specimens shows that this feature is variable. Recent examples have generally prominent almost sharp spines on the two last whorls. One specimen from Rouen Village shows a decided resemblance to the Bowden fossil *S. pugiloides* Guppy but is larger; it has very low spines on the body whorl but does not narrow anteriorly so rapidly as does *S. pugiloides.*

Strombus gigas Linn.

I have never seen this large shell in a good enough condition to make a close comparison with recent specimens, but one I collected at Rouen looked decidedly smaller and the outer lip thicker.

Strombus bituberculatus Lam.
Cerithium atratum Born.
Cerithium litteratum Born.
Cerithium caudatum Sow.

Modulus lenticularis Chem.
Caecum sp.
Vermetus cf. *erectus* Dall.
Turritella cf. *exoleta* Linn.

Old-looking coral rock near Consett Point.

Omphalius fasciata Born.
Calliostoma cf. *javanicus* Lam. or *C. zonamestum* A. Ad.

A shell from low levels resembles the above species, but with the base less excavated and the body whorl less angular below.

Torinia cyclostoma Menke.
Hipponyx intortus Lam.
Hipponyx antiquatus Linn.

Casts at 1,000 feet, common at low levels.

Calyptra (*Mitrularia*) cf. *Dillwynii* Gray or *C. equestris* Linn. or *C. uncinata* Reeve. (Pl. IV, Figs. 8 and 9.)

A perfect specimen at 10 feet altitude in coral rock cliff at St. Lawrence and a cast from Canefield at 1,000 feet.

Natica (*Polinices*) *uberina* D'Orb.
Natica (*Polinices*) *porcellana* D'Orb.
Obeliscus (*Pyramidella*) *dolabratus* Linn.

Smooth thin-shelled specimens at low levels the teeth in the outer lip faint.

Nerita peloronta Linn.

This common conspicuous recent " bleeding tooth " shell is very rare in the coral rock at low levels.

Nerita tessellata Gmel.
Nerita versicolor Lam.
Astralium (*Lithopoma*) *imbricata* Gmel.

Casts at Canefield 1,000 feet, Hackleston's Cliff 900 feet, common at low levels. Very variable some specimens resembling the Panama form *A. unguis* Wood.

Astralium (*Lithopoma*) *caelatura* Chem.
Liotia (*Arene*) *radiata* Kiener.
Livonia pica Linn.

This is the Turbo-like shell with horny *Littorina*-like operculum. Large specimens occur at Hackleston's cliff and elsewhere at 900 feet and it is common at low levels.

Fissurella barbadensis Gmel.

One specimen at Ragged Point. The recent shell occurs everywhere between tide marks.

Glyphis alternata Say.
Lucapina cancellata Sow.

Hemitoma (*Emarginula*) *imbricata* A. Ad.
Acmaea near *Cubensis* Reeve.

Common at low levels.

The Oceanic Series.

It has not yet been determined whether these are Miocene or Pliocene. They are not in any way folded as the underlying Scotland beds are but they had suffered faulting, tilting and erosion —probably submarine erosion—before the beginning of coral rock deposition. The Oceanics are absent from many parts of Barbados but may appear in full thickness a short distance away.

At Bissex Hill which goes up to about 980 feet altitude the Oceanics pass up into a series of hard limestones; the section as I observed it recently there is as follows:—

	Thickness in feet.
Thinly bedded grey and brown slabby calcareous rock, in places an echinoderm breccia with small phosphatic fragments. Fossils, simple turbinate corals of the *Trochocyathus* type; small sharks' teeth; poorly preserved mollusca including a *Tellina* and a thin-shelled *Pecten* with rounded ribs and flattish interspaces 27 mm. in size, the ears and margins damaged	25
Dense grey and yellow calcite veined limestone in large blue-hearted masses	30 (?)
Unconformity (?) but the junction too much obscured to be sure of this. The beds above this are generally called the Bissex Hill beds.	
Grey calcareous rather nodular rock	5
Yellow compact Oceanic beds brown at the top	40
Brown marly Oceanic beds full of large *Globigerinae* weathering into a soft brown material in which occurred the dorsal valve of a *Brachiopod* much resembling *Eudesia floridana* [1] Pourtales	5
Unconformity.	
Scotland beds	?

The best preserved large mollusc described from these beds is *Scalaria ehrenbergi* E. Forbes, illustrated in Sir R. Schomburgk's *History of Barbados*, 565, fig. 1. It is said to be allied to some Tertiary forms probably Miocene and its nearest living ally is *S. crassilabrum* Sow. from the Philippines and Central America. It came from a siliceous limestone near the summit of Bissex Hill.

The supposition that the echinoderm *Cystechinus crassus* described by Professor J. W. Gregory [2] from the Oceanics at Haynesfield necessarily indicates very deep water conditions seems to have been somewhat discounted by the record of the same genus from the Suva soapstones of Fiji which are said to be associated with a shallow water limestone.[1] Another interesting echinoderm is *Archaeopneustes abruptus* Gregory from Bissex Hill.[2]

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[1] Dall, *Bull. U.S. Nat. Museum*, No. 37, 1889, pl. xxxix, fig. 9. The range in depth of this given as 119–310 fathoms and the geographical range as Sandy Key to Barbados.

[2] *Quart. Jour. Geol. Soc.*, xlv, 1889, 640–650.

True coral rock is not found on Bissex Hill but the small turbinate corals in the beds that cap the hill may be the same as similar forms found at the base of the coral rock at Chimborazo and the Bissex Hill beds may actually have passed up into coral rock but at Chimborazo and other places along the escarpment wherever a clear section is visible the base of the coral rock rests unconformably on *Globigerina* chalks or other beds of the true Oceanic series.

The Oceanics have been described in detail by J. B. Harrison and other writers,[3] who estimate the maximum thickness of the series at Mt. Hillaby as 325 feet.

Dr. C. A. Matley in a recent paper on the " Old Basement of Barbados " (GEOL. MAG., Aug., 1932, 366), reminds us that Mr. A. Beeby Thompson has recorded a boring in the south part of the island where the Oceanic beds were 2,000 feet thick or more. This boring went down 3,200 feet and failed to pierce them. Perhaps tilting or thrusting may help to account for the abnormal thickening of the Oceanics here, or possibly deposition on a shelf.

The Scotland Beds.

These form the foundation of the island and Mr. A. Beeby Thompson [4] has described the tectonic structure as revealed during the investigation for oil. He quotes the formations of Barbados as follows, dividing the Scotland series into a number of beds :—

CORAL.

Unconformity.

Oceanic Series up to 2,000 feet or more.

Unconformity.

Joe's River Clay, up to a few hundred feet thick, a series of dead black oil soaked clay, the debris of former mud volcanoes.

Unconformity.

Chalky Mount and Mt. All beds ; coarse and fine grained sands and interbedded clays with fossil conglomerate at the base.

St. Andrew's beds ; fine sands, clays and limestone bands the upper part oil impregnated and highly folded, the base nowhere exposed.

Below these, if one must have geographical terms I should like to place the unfossiliferous Ragged Point beds exposed at the south-east corner of Barbados which are probably the lowest Scotland beds visible in the island.

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[1] C. A. Matley and A. Morley Davies, GEOL. MAG., LXIV, No. 752, February, 1927, 69.

[2] *Quart. Jour. Geol. Soc.*, xlviii, 1892, 163.

[3] G. F. Franks and J. B. Harrison, " The Globigerina marls of Barbados " : *Quart. Jour. Geol. Soc.*, liv, 1898, 540–555. And *The Geol. of Barbados.* Part II. " The Oceanic Deposits " : A. J. Jukes-Browne and J. B. H. : *Quart. Jour. Geol. Soc.*, xlviii, 1892, 170–226.

[4] *Oil Field Principles*, i, London, 1925, 394–6.

The following observations of dips etc. may be of interest. The localities are given as one proceeds from the north where the highest beds are presumed to occur to the south-east where the lower beds are met with at Ragged Point.

1. Spring Hall inlier, fine-grained light brown sandstones dip at a low angle to the north-west.
2. Near Boscobelle finely laminated sandstones and clay ironstones at a high angle to the north-east (Harrison and Jukes-Browne).
3. Chalky Mount beds dip at 70–80 degrees north but the strike curves.
4. Sunbeam below the foot of Turner's Hall Wood beds including the fossiliferous conglomerate dip north-west at very steep angles.
5. Spa, the fossil conglomerate and other beds dip north-north-west, but are nearly vertical.
6. Ragged Point. Coarse grits and underlying shales, unfossiliferous, dip to the north-west at about 30 degrees.

The direction whence the material of the Scotland beds was derived is uncertain but on the ridge at Sunbeam in the fossiliferous conglomerate which is chiefly made up of clay ironstone, small quartz pebbles etc. I collected a small piece of white crystalline limestone or marble. It is a small pebble fractured across and recalls the Crystalline limestones in the schists of the Northern Range of Trinidad and may have come from that direction or from similar land now foundered. Another source for crystalline limestone is the Isle of Pines off the south-west coast of Cuba but that is much further away.

Dr. Matley gives a list of minerals found in the conglomerate of the Scotland beds at Chalky Mount. Sir J. B. Harrison [1] wrote to me in 1925 and supplied lists of minerals he had detected in the Scotland sandstones as follows :—

Mt. Poyer sandstone (*north of island*), abundant plates of green and olive hornblende with ragged edges and some brown hornblende. A few grains of corundum, topaz, and red garnet. Hypersthene scarce, minute crystals. Magnetite grains abundant ; haematite scarce ; pyrite grains scarce.

Chalky Mount sandstone, pyrite abundant ; tourmaline, some grains ; corundum fragments scarce ; zircon and topaz a few small crystals ; hornblende, in green, olive and brown plates fairly abundant ; magnetite a few grains, scarce ; haematite, sparse ; garnet, brownish, a few grains.

Ragged Point sandstone, zircon abundant small prisms, some rounded ; smaller grains crystalline and sharply angular. Plates of green and olive hornblende ; corundum angular fragments ; brown tourmaline, minute crystals, scarce; topaz fine grains rather common; red garnet small granules scarce; plates of orthoclase scarce; grains of magnetite abundant. Spinel in minute grains, very scarce; allanite, a few minute prisms; epidote grains scarce; sphene grains very scarce.

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[1] I have already quoted from this letter, a very few weeks after receiving it I heard the sad news that the distinguished writer had been taken suddenly ill with malignant malaria in his office in Demarara and had died a few days later.

Sir J. B. Harrison remarks in this letter, "Careful examination of the coarse sandstones showed that they had been derived from granite, here and there in them were fragments of felspar largely converted into kaolin while I found a very few pebbles of almost completely decomposed granite.

There is a possibility, but I think it is a remote one, that all or part of the Scotland beds may be of Oligocene age. Among three or four species of *Callianassa* which are described by Mr. T. H. Withers, F.G.S.,[1] one seems to be the same and another closely related to a *Callianassa* recorded from the Culebra Formation, said to be Middle and Upper Oligocene of Panama. The bulk of the mollusca in the small conglomerate bed in which the *Callianassa* occurred are of Eocene aspect though some have been and others may have been derived from a previously existing bed or beds. Thus in the conglomerate at Spa I found a sandstone pebble with a freshwater bivalve resembling the thin-shelled recent African genus *Cyrenoidea*, evidently derived from a bed such as the one containing *Unionidae*, *Ampullariae* etc. that occurs about 150 feet below the conglomerate. Derived and rolled nodules containing Foraminifera and also *Callianassa* claws occur in the conglomerate at Spa and other localities. In spite of the fact that some of the fossils in the conglomerate have been derived I still think that the main portion of the Scotland beds is of later Eocene age.

Some of the fossils in this bed seem to show decided African affinities. A large *Ampullaria* occurs in masses of the freshwater sandstone in parts of the Scotland area. I have referred to this bed in a former paper[2] and compared the *Ampullaria* with various recent forms from Trinidad and South America. During a visit to Ripon Falls on Lake Victoria Nyanza however I collected a number of the *Ampullaria gordoni* Smith[3] which lie about there in plenty and find that the Central African shell agrees much more nearly with the Barbados fossil than do any of the South American or Eastern forms. In height of spire, gradual increase of the early whorls and their erosion, depth of suture, rounding of whorls, slightness or absence of umbilicus and in the coarse foliaceous growth lines and thickness of shell the resemblance is close. The Barbados fossil however is larger and the aperture more circular and the last whorl is more inflated anteriorly than in the African *A. gordoni*.

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[1] "Decapod Crustaceans from Barbados": GEOL. MAG., LXIII, 1926, 104.

[2] GEOL. MAG., LXII, 1925, 484.

[3] *Ann. and Mag. Nat. Hist.*, x, 1892, 382.

Several beds of the Scotland series are of freshwater origin; there is an impure sandy limestone about 20 feet thick above the fossiliferous conglomerate at Spa; it stands vertically where the path along the ridge descends on approaching the locality from the west. Recently I collected a small elongate thin-shelled bivalve looking like a *Unio*, badly preserved, but evidently a freshwater form.

Some additional species of fossils have turned up in the conglomerate bed at Spa, among them a well-preserved small echinoderm. Professor H. L. Hawkins has kindly examined this and reports "I find it to be a *Breynella*, as far as I can tell it is a new species, but it shows pretty close affinity with *B. gregoryi* Twitchell. *B. gregoryi* is recorded from the Upper Middle, or perchance Lower Upper part of the Eocene in South Carolina."

Regarding the Foraminifera that occur in rolled pebbles together with *Lithothamnion* in the conglomerate bed Professor A. Morley Davies writes "One pebble is full of a small *Discocyclina* which on the evidence of external appearance and random sections, may be provisionally compared with *D. varians* Kaufmann; another is full of *Nummulites variolarius* Lamarck. The latter points to a definitely Upper Eocene age (Auversian = Ledian)."

CONCLUSIONS.

The following conclusions have been arrived at after a rather long acquaintance with Barbados.

1. All or practically all the coral rock covering, except certain veneers of coastal beach rock and possibly some coral rock at lowest levels along the west coast, was formed before the uplift commenced, and the highest coral rock is not necessarily the oldest as has been previously supposed.
2. The coral rock attains its maximum thickness of 240–250 feet at some of the highest parts of the island, Hackleston's cliff 997 feet altitude, Edgecliff 829 feet altitude, Bowmanston 600 feet altitude etc.
3. The uplift has not been directly vertical, but an oblique or differential one; the higher part of the island has been tilted or thrust towards the east and north, followed by later repeated uprising with slighter tilting, the force extending outwards and directed from the west and south. The southern Christchurch dome is due to later upward bending.
4. As a result of the tilting the higher parts of the coral rock covering have been fractured and denuded off, exposing the underlying Oceanics and Scotland beds over the Scotland area.
5. At the base of the coral rock along the escarpment overlooking the Scotland area there is a bed full of *Amphistegina lessoni*; if this foraminiferon indicates rather deep water conditions, the higher

parts of the island may have been the deepest at the beginning of coral rock times.

6. The edges of the benches of coral rock at several levels are in some cases so vertical and smooth as to appear to be due to fault scarps assisted by wave action. In other parts they are more clearly due to coast erosion possibly the result of periodical rises of sea-level as the uplift continued. At the present time the sea is undercutting most of the coral rock cliffs around the island.

7. The outer edges of each of the coral rock beaches along the straight west side of the island and also along the south side are generally rather higher than the inner portion. This seems to be a tectonic feature due to later uprise and tilting from the south and west, rather than a feature due to lagoon formation inside a coral reef.

8. The coral rock covering once extended higher and further to the east than it now does and probably extended all over the Scotland area. Some of the valleys and gorges that pass down the westerly dip slope open up on the edge of the elevated coral rock escarpment and have been beheaded by the slipping away of masses of coral rock down the Scotland area.

9. The north-eastern coastal platform of the island at 60–100 feet altitude shows evidence of late scouring by the sea as mushroom-shaped undercut masses of coral rock occur at the foot of the first steep inland cliff and patches of underlying Oceanics are exposed nearby. The south-east coastal area at about the same altitude seems to have been similarly wave-cut.

10. The mollusca in the coral rock at high levels do not seem to differ from those at medium or low levels but even at low levels a certain number show perceptible differences from the living species, while a few are Panama forms. At the base of the coral rock but independently of level a few forms suggestive of the Pliocene were collected, especially in the south-east around Consett Point where an old-looking dense coral rock occurs. No rock however resembling the Antigua limestone was noticed. The mollusc fauna of the main portion of the coral rock seems to be fairly early Pleistocene, and later than that of the limestones of Brimstone Hill, St. Kitts.

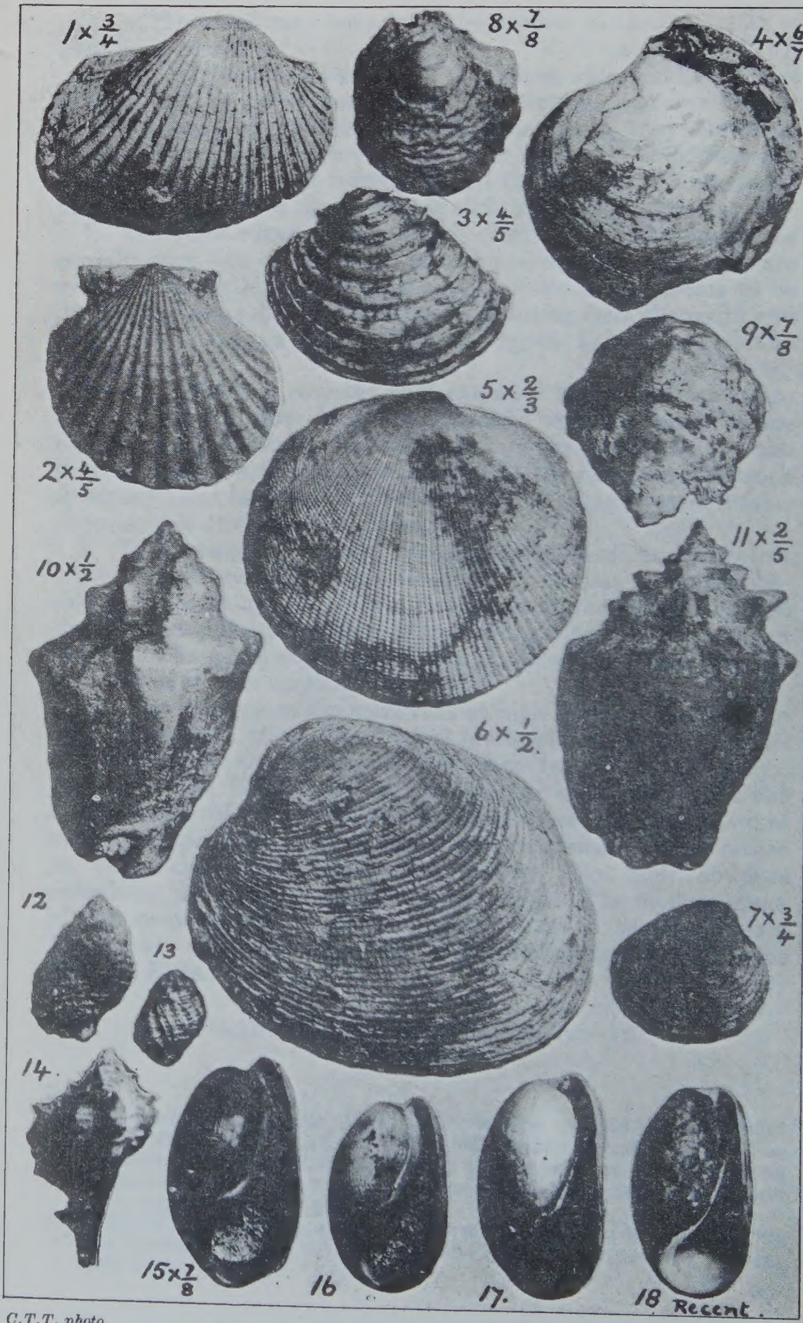
EXPLANATION OF PLATES III AND IV.

PLATE III.

FIG.

1.—View from the south side of Gay's Cove looking towards the north point of the island. On the left is a cliff of old weathered coral rock near Pico Teneriffe. In the distance is the gently sloping platform of the north end of Barbados; the cliffs at the base are formed of Oceanic chalks overlain by a varying thickness of coral rock.

2.—Profile of the rising terraces of coral rock north-east of Bridgetown showing the benches higher on the outer side and sinking down towards the next cliff or rise.



C.T.T. photo.

FOSSILS FROM THE CORAL ROCK OF BARBADOS AND ONE RECENT BULLA.

To face p. 47.]

FIG.

3.—Inland cliff or escarpment of coral rock about 1½ miles north-west of Gay's Cove, standing at an elevation of about 100 feet above sea-level. At the foot of the cliff are masses of coral rock some of them fallen from the cliff, undercut by the sea at some later period. The coast eroded platform is now occupied by sugar-cane fields.

4.—View from Gay's Cove looking south-east towards Pico Teneriffe. In the foreground thick *globigerina* chalks of the Oceanic Series dip to the east; on the opposite side of the bay they are overlain by old weathered coral rock at the base of which is a bed of conglomerate of white limestone pebbles.

PLATE IV.

1.—*Scapharca* cf. *Deshayesi* Hanl. var. 2. Right valve, three-quarters natural size. Rouen Village. 150 feet altitude.

2.—*Pecten* (*Chlamys*) cf. *irradians* Lam. Slightly reduced. Lower coral rock near Consett Point.

3.—*Chione paphia* Linn. cf var. *Christopheri* Trechm. Reduced. Rouen Village.

4.—*Cyclina* near *C. subquadrata* Hanley. Slightly reduced. Rouen Village.

5.—*Codakia orbicularis* Linn. var. Two-thirds natural size. Savannah near Bridgetown. About 40 feet elevation.

6.—*Chione multicostata* Sow. var. Left valve about one-half natural size. Rouen Village. 150 feet altitude.

7.—*Chione cancellata* Linn. a variety resembling the Bowden species *C. Woodwardi* Guppy. Three-quarters natural size. Base of Coral Rock near Gay's Cove.

8.—*Calyptra* (*Mitrularia*) cf. *Dillwynii* Gray. Reduced. A specimen from 10 feet altitude at St. Lawrence near Hastings.

9.—Ditto, a cast from Canefield 1,000 feet altitude.

10.—*Voluta musica* Linn. var. One-half natural size. From Hastings about 20 feet altitude.

11.—*Strombus pugilis* Linn. var. with few spines on body whorl. About two-fifths natural size. Low levels near Bridgetown.

12 and 13.—*Coralliophila Barbadensis.* Sp. nov. About natural size, from low level coral rock near Hastings.

14.—*Murex* (*Haustillum*) *messorius* Sow. Slightly reduced, from low level coral rock near the west coast.

15, 16, 17.—*Bulla*, cf. *Vendryesiana* Guppy. Slightly reduced. Figs 15 and 16 from low level coral rock near Hastings, Fig. 17 from basal coral rock at Gay's Cove.

18.—*Bulla striata* Brug or *B. maculosa* Mart., Recent from Barbados to show the shorter aperture and less everted aperture and callosity than in the fossil form.

CORRESPONDENCE.

ASSIMILATION OF LIMESTONE AT LOCH BOROLAN.

SIR,—In the *Summary of Progress* of the Geological Survey for 1930, Dr. J. Phemister has a short note on a carbonate rock occurring at Bad na h'Achlaise, Sutherlandshire, which I described in 1910. The rock appears in association with melanite-pyroxenite ("cromaltite"), and in my inexperience I took it to be a limestone which had been metamorphosed by contact with the latter rock.

Dr. Phemister now shows that the carbonate rock is an alteration-product of the cromaltite—a perfectly likely conclusion with which I have no wish to quarrel. But when he claims that this " removes the only piece of direct evidence which has so far been advanced in favour of assimilation of limestone in the Cnoc-na-Sroine (Loch Borolan) laccolite " he goes too far and too fast. He adds that in a recent paper of mine (GEOL. MAG., 1930, 415) I quoted the Bad na h'Achlaise locality as one where there is " clear evidence of desilication of magma by limestone ". Neither in my 1930 paper, nor in my 1910 paper did I make any such claim about Bad na h'Achlaise. What I did claim is that in the Loch Borolan area *as a whole,* there is such evidence. Whether it is " direct " or not is a question of definition ; does Dr. Phemister expect me to show him a hot magma making a meal of limestone before he will be convinced ?

The evidence of assimilation of limestone at Loch Borolan may be summarized as follows :—

(1) The Cnoc-na-Sroine complex as a whole is intrusive in the Durness Limestone, and is believed to have a limestone floor. This was the opinion of Horne and Teall, and it has not so far been questioned. Limestone is exposed all round the hill, although actual contact is only seen at a few points on the north and east. In addition, a rock which I took to be a metamorphosed limestone has been brought up along a thrust-plane between syenite and borolanite in the stream Aultivullin.

(2) All the rocks that are seen in contact with limestone, and all those that lie nearest to the supposed floor of the laccolith, are rich in melanite and diopside (" aegirine-augite ").

(3) Diopside is a characteristic product wherever magnesian limestone becomes silicified at an igneous contact. Melanite is an uncommon mineral of which almost every known example occurs at a limestone contact.

(4) Granitic magmas like that of Cnoc-na-Sroine do not give rise to melanite-syenites and diopside-melanite rocks without some very special and *local* cause. The days are past when one could talk vaguely of " magmatic differentiation " and hope to get away with it. The only conceivable reason that anybody has ever been able to suggest for the development of the melanite rocks at Loch Borolan is assimilation of limestone, and there is no theoretical or factual objection to the suggestion.

Dr. Phemister is right to be critical, but in this instance I think he is being captious.

S. J. SHAND.

STELLENBOSCH, S. AFRICA.
18*th April,* 1932.